Final Report

"Further Detailed Analysis of Telemetry Records Obtained by Explorer IV Satellite Concerning Geomagnetically Trapped Radiation"

Defense Atomic Support Agency, Washington, D. C., 20301;
Contract No. DA-49-146-XZ-494: "Research concerning analysis of telemetry records."
Period of contract: 1 November 1965 - 30 November 1966

Personnel
A. H. Weber, Principal Investigator
A. F. Briskien, Graduate Student, M.S. program (physics)
M. E. Coughlin, Undergraduate Research Aide
J. F. Fannell, Graduate Student, Ph.D. program (physics)
J. A. George, Associate Professor of Aerospace Engineering, Parks College, Saint Louis University
Wm. K. Kottmeyer, Graduate Student, M.S. program (physics)
D. J. Manson, Post-doctorate Research Associate
J. R. Ockerson, S.J., Graduate Student, M.S. program (physics)
J. H. Paikeday, Post-doctorate Research Associate

DASA Project Officer Dr. Charles A. Blank
Radiation Division
Defense Atomic Support Agency
Department of Defense
Washington, D. C.

Reproduction of this report in whole or in part is permitted for any purpose of the United States Government.

30 November 1966
Saint Louis University
Physics Department
St. Louis, Missouri 63103
Acknowledgments

1. This research was supported by the Department of Defense, Defense Atomic Support Agency, Radiation Division, under Contract No. DA-49-146-XZ-494. In addition to the funding support of DASA, the authors wish to express their considerable appreciation of the valued cooperation and help of Dr. Charles A. Blank of the same division.

2. Dr. Juergen K. Bock, recently of the Nuclear Physics Branch of the Ballistic Research Laboratories, Aberdeen Proving Ground, Maryland, rendered essential scientific aid in the present work. E. O. Baicy, Chief of the Nuclear Physics Branch of BRL was instrumental in effecting scientific liaison between his branch and the group in the physics department of Saint Louis University. The assistance of BRL in this scientific work was indispensable.

3. The Yalem Computer Center, Saint Louis University, rendered invaluable services via unrestricted time on the IBM-1620 Computer.

4. Washington University Computing Facilities, through National Science Foundation Grant G-22296, rendered valuable assistance and support of the present project during the last three months of the contract period.

5. The assistance of Messrs. Roy Cochran and D. G. Aichele of the staff of the Computation Laboratory, George C. Marshall Space Flight Center, Huntsville, Alabama is especially acknowledged. These computer experts provided a new group of "playbacks" of the set of telemetry tapes selected for analysis in the present work. These playbacks were much superior in elimination of noise and clarity of record to the group of records which were originally available. The availability of these new high quality playbacks enabled considerable improvement in the analysis.
Contents

Acknowledgments

Contents

Abstract

P1. Preface - Glossary

P2. Preface - Calibrations, Corrections and Telemetry Information

Part A. Summary of Ph.D. Dissertation, Donald J. Manson, "Van Allen Radiation Belt and ARGUS Directional Flux Density Distributions; Explorer 4, Satellite Data"; Saint Louis University, Physics Department, February 1967.

Part B. Summary of M.S. Thesis of Joseph F. Fennell, "Van Allen Belt and ARGUS Directional Flux Density Distributions; Explorer 4 Satellite Data, ARGUS Event 2"; Saint Louis University, Physics Department, July 1966.

Part C. Summary of Ph.D. Dissertation, John A. George, "Omnidirectional Fluxes; Explorer 4 Satellite Data, ARGUS Events 1 and 2"; Saint Louis University, Physics Department, February 1967.


Part E. Summary of Pertinent Analytic Sections of Ph.D. Dissertation, Joseph M. Paikeday, "Interpretation of Directional Flux Densities in ARGUS Shells; Explorer 4 Satellite Data"; Saint Louis University, Physics Department, March 1966.

Page

P1-1 to P1-7

P2-1, P2-3

A1-A14

B1-B13

C1-C30

D1-D8

E1-E3
Abstract

This report (Preface P1, P2; Parts A-E) is essentially a summary of the five M.S. Theses and Ph.D. Dissertations completed during the contract year for contract No. DA-49-146-XZ-494. The titles of these theses and dissertations are the heading titles for each of the five Parts A-E.

This Final Report is more than a mere summary since all results have been condensed, compared, corrected and interpreted as a group. Figures A8, C14 and D4 exhibit count-rates and/or particle flux densities, both for the Natural and the ARGUS Events 1 and 2 radiations, in 3-dimensional B-L coordinates. These 3-dimensional plots exhibit most clearly the coordination of all the data and are presented for the first time in this Summary Final Report.
<table>
<thead>
<tr>
<th>SYMBOL</th>
<th>DEFINITION</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Nucleon number (Ref. P1, Sec. 1)</td>
</tr>
<tr>
<td>(A)</td>
<td>Vector, along axis of minimum moment of inertia Explorer 4. Also the direction of the satellite symmetry axis. (Ref. P1, Fig. 2.2).</td>
</tr>
<tr>
<td>(A_{\text{eff}})</td>
<td>Effective area (product of counter efficiency and geometric area (A)) of directional counter Explorer 4 (cm²)</td>
</tr>
<tr>
<td>(a_i)</td>
<td>Scale height for atmospheric model defined by (a_i = \frac{1}{h_{i+1} - h_i} \ln \frac{N_i}{N_{i+1}}), where (N_i = \text{number/unit volume at altitude } h_i) where (h_i) is the altitude in kilometers (Ref. P2)</td>
</tr>
<tr>
<td>a</td>
<td>Equatorial radius of international ellipsoid (km)</td>
</tr>
<tr>
<td>(A_p)</td>
<td>Daily equivalent planetary amplitude (Ref. P3, Sec. 1.5)</td>
</tr>
<tr>
<td>(a_p)</td>
<td>Three-hour equivalent planetary amplitude (Ref. P3, Sec. 1.5)</td>
</tr>
<tr>
<td>(\mathbf{B})</td>
<td>Geomagnetic flux density vector (gauss)</td>
</tr>
<tr>
<td>(\mathbf{B})</td>
<td>Geomagnetic flux density unit vector, (\mathbf{B}/B)</td>
</tr>
<tr>
<td>(\mathbf{B}_0)</td>
<td>Magnetic flux density unit vector at the time the satellite inertial coordinate system is established (time of any rf-null prior to data to be analyzed)</td>
</tr>
<tr>
<td>(B_m)</td>
<td>Mirror point value of (B) (gauss)</td>
</tr>
<tr>
<td>(B_A)</td>
<td>A vector in the plane perpendicular to the magnetic flux density vector (B) (gauss)</td>
</tr>
<tr>
<td>(B_{x}, B_{y}, B_{z})</td>
<td>Components of a unit vector (B) in Vernal Equinox coordinates</td>
</tr>
<tr>
<td>(B_e)</td>
<td>Equatorial value of (B)</td>
</tr>
<tr>
<td>b</td>
<td>Polar radius of international ellipsoid</td>
</tr>
<tr>
<td>(b_1, b_2, b_3)</td>
<td>Components of (B) on the (X, Y, Z) axes of satellite inertial coordinate system (Ref. P1, Eq. (3.14))</td>
</tr>
<tr>
<td>Symbol</td>
<td>Definition</td>
</tr>
<tr>
<td>--------</td>
<td>------------</td>
</tr>
<tr>
<td>$b_n, b_e, b_d$</td>
<td>Normalized (divided by B) components in topcentric coordinate system of ephemeris (north, east, down)</td>
</tr>
<tr>
<td>$C$</td>
<td>Omnidirectional count-rate corrected for deadtime (sec$^{-1}$)</td>
</tr>
<tr>
<td>$c$</td>
<td>Speed of light in free space</td>
</tr>
<tr>
<td>$C'$</td>
<td>Observed count-rate corrected for counter dead-time (sec$^{-1}$)</td>
</tr>
<tr>
<td>$C_{obs}(\theta)$</td>
<td>Observed directional count-rate for detector A (sec$^{-1}$)</td>
</tr>
<tr>
<td>$C_{obs}$</td>
<td>Omnidirectional observed count-rate (sec$^{-1}$)</td>
</tr>
<tr>
<td>$C(\theta)$</td>
<td>True directional count-rate ($C_{obs}(\theta)$ corrected for deadtime, efficiency and effective area) (sec$^{-1}$ cm$^{-2}$)</td>
</tr>
<tr>
<td>$C(\mathbf{r})$</td>
<td>Auto-covariance function (Ref. P1, P4, Eq. (A1.2))</td>
</tr>
<tr>
<td>$E$</td>
<td>Kinetic energy of a particle</td>
</tr>
<tr>
<td>$\mathbf{E}$</td>
<td>Electric field vector</td>
</tr>
<tr>
<td>$e$</td>
<td>Electronic charge</td>
</tr>
<tr>
<td>$f(h')$</td>
<td>Mirror-point density (Ref. P2, Eq. (2.24))</td>
</tr>
<tr>
<td>$F(\boldsymbol{\alpha}, \phi),d\Omega$</td>
<td>Fraction of particles with directions within $d\Omega$ at $(\boldsymbol{\alpha}, \phi)$ (Ref. P3, Sec. 4.5)</td>
</tr>
<tr>
<td>$(f)$</td>
<td>Fraction of fission electrons that penetrate a shielding (Ref. P3, Sec. 2.4)</td>
</tr>
<tr>
<td>$H$</td>
<td>Receiver antenna height above the international ellipsoid (mean sea level) (earth radii)</td>
</tr>
<tr>
<td>$H, H_R$</td>
<td>Relativistic Hamiltonian (Ref. P3, Sec. 3.2)</td>
</tr>
<tr>
<td>$h$</td>
<td>Distance measured from the center of the earth to a field line (km)</td>
</tr>
<tr>
<td>$I$</td>
<td>Parameter related to the longitudinal invariant (Ref. P3, Eq. (3.22))</td>
</tr>
<tr>
<td>$I(E)$</td>
<td>Omnidirectional intensity of particles with energy greater than E (Ref. P3, Eq. (4.38))</td>
</tr>
<tr>
<td>$i(E)$</td>
<td>Omnidirectional spectral intensity (Ref. P3, Eq. (4.32))</td>
</tr>
<tr>
<td>$I_p(x)$</td>
<td>Modified Bessel function of order p</td>
</tr>
<tr>
<td>$I_{x'}$</td>
<td>Moment of inertia about the $X'$ axis</td>
</tr>
<tr>
<td>$I_{y'}$</td>
<td>Moment of inertia about the $Y'$ axis</td>
</tr>
</tbody>
</table>
\( I_z \)
Moment of inertia about the \( Z' \) axis

\( J_1(x) \)
First order Bessel function regular at the origins

\( j(\alpha, \phi; E) \)
Unidirectional spectral intensity (Ref. P3, Eq. (4.32))

\( J_0(\theta') \)
Directional flux density of particles as a function of angle between \( J \) and a plane perpendicular to \( B \)

\( J_o \)
Omnidirectional flux density (particles cm\(^{-2}\)sec\(^{-1}\))

\( L \)
Length of nose cone and instrument section Explorer 4

\( \hat{l} \)
Angular momentum unit vector

\( L \)
McIlwain's geomagnetic shell parameter (earth radii)

\( M \)
Earth dipole moment (Ref. P3, Eq. (1.9))

\( m \)
Relativistic mass of electron

\( m_0 \)
Rest mass of electron

\( N \)
The number of digitizer counts per digitizing interval \( T \)

\( N(E) \)
Absolute differential spectral intensity, electrons/fission/MeV (Ref. P3, Eq. (1.5))

\( n_{i+1} - n_i \)
The number of digitizer counts measured to correspond to one frequency change (flip) on data record

\( n \)
Index of refraction (Ref. P3, Eq. (4.10))

\( \overset{\rightarrow}{P} \)
Relativistic particle momentum; also a transformation parameter in the conversion from B-L to R-X (Ref. P3, Eq. (1.13))

\( \overset{\hat{}}{P} \)
Counter symmetry axis unit vector

\( P_{\perp} \)
Component of particle momentum perpendicular to the magnetic flux density vector \( B \)

\( P_{\parallel} \)
Component of particle momentum parallel to the magnetic flux density vector \( B \)

\( P(f) \)
Relative spectral intensity of frequency \( f \) (Ref. P1, Eq. (A1.1))

\( r \)
Distance of a particle from the center of the earth (km)

\( \overset{\rightarrow}{R} \)
Vector from center of earth to tracking station in Vernal Equinox coordinates (km)
\( \vec{r} \) Vector from center of earth to satellite in Vernal Equinox coordinates (km)

\( R_e \) Radius of the earth, \( 0.63712 \times 10^7 \) meters

\( r_e \) Equatorial distance from dipole center to B line (km)

\( R_E \) Extrapolated range of particles penetrating an absorber (Ref. P1, P3, P4; \( \text{gm cm}^{-2} \))

\( R_{1/2} \) Range for 50 percent transmission of radiation through an absorber (\( \text{gm cm}^{-2} \))

\( S \) Scaling factor - twice the number of accumulated particle counts corresponding to one frequency change on the data record (particle counts per flip-flop)

\( s \) Normalized particle momentum (Ref. P3, Sec. 4.23)

\( S(\infty) \) Detector A response function (Ref. P4)

\( S_{ij} \) Matrix element representing the kernel of the integral equation relating the true count-rate \( C(\theta) \) and the directional flux density \( J(\theta') \)

\( S(p) \) A parameter in the transformation from B-L to R-\( \lambda \) (Ref. P3, Eq. (1.14))

\( T \) Time interval selected for digitization (usually 24 sec)

\( T_a \) Longitudinal drift period (Ref. P3, Eq. (3.29))

\( T_b \) Bounce period (Ref. P3, Sec. 3.26) (sec)

\( T_g \) Cyclotron period (Ref. P3, Eq. (3.9)) (sec)

\( T(\lambda) \) Bounce period of a particle with mirror-point at latitude \( \lambda \) defined by Eq. (2.8) (Ref. P2) (sec)

\( t_i \) Time at which particle count-rate for interval between frequency change (flip) is assigned (center of interval) (UT min)

\( t_0 \) Initial time of time interval \( T \) (UT min)

\( \vec{U} \) Vector from tracking station to satellite

\( \vec{V}_A \) Alfvén velocity (Ref. P3, Eq. (4.6)) (km sec\(^{-1}\))

\( v \) Speed of particle

\( W \) Total energy (Ref. P3, Sec. 3.2)

\( X' \) Axis of maximum moment of inertia Explorer 4
\( \hat{X}, \hat{Y}, \hat{Z} \) Axes of Vernal Equinox inertial coordinate system; \( \hat{X} \) in direction of Vernal Equinox of 1951; \( \hat{Y} \) in earth's equatorial plane; \( \hat{Z} \) to form right hand orthogonal system

\( \hat{X}_r, \hat{Y}_r, \hat{Z}_r \) Axes of satellite fixed rotating coordinate system; \( \hat{X}_r \) space fixed in direction of angular momentum vector \( \mathbf{L} \); \( \hat{Y}_r \) in the direction of satellite symmetry vector \( \mathbf{A} \) (rotating in a plane perpendicular to \( \mathbf{L} \) in propeller-like motion); \( \hat{Z}_r \) to form a right-hand orthogonal system

\( \hat{X}_s, \hat{Y}_s, \hat{Z}_s \) Axes of satellite inertial coordinate system; \( \hat{X}_s \) in direction of angular momentum vector \( \mathbf{L} \); \( \hat{X}_s-\hat{Y}_s \) plane oriented to include \( \mathbf{B} \) the magnetic flux density unit vector at time zero when an \( \mathbf{E}-\mathbf{B} \) null is observed; \( \hat{Z}_s \) to form a right-hand orthogonal system

\( Y_1(x) \) First order Bessel function irregular at the origin

\( Z \) Atomic number of scattering atoms

\( Z' \) Axis of minimum moment of inertia Explorer 4

\( \phi \) Pitch angle. The angle between the particle momentum vector and the magnetic flux density vector (deg)

\( \alpha_c \) Pitch angle of the particle that defines the loss cone (deg)

\( \beta \) Ratio of particle speed to speed of light in free space

\( \gamma \) Relativistic mass ratio (Ref. P3), Spectral exponent (Ref. P3, Eq. (4.19))

\( \gamma \) Phase angle of tumble motion of satellite

\( \Delta \) Geodetic latitude (radian)

\( \Delta' \) Geocentric latitude (radian)

\( \Delta_s \) Geocentric latitude of satellite (radian)

\( \delta \) Phase angle of roll (spin) motion of satellite

\( \epsilon \) Detection efficiency of counter

\( \eta \) Minimum scattering angle (Ref. P2) (deg)

\( \Theta \) Hour angle of the Vernal Equinox (radian)

\( \Theta_{8i} \) Angle between the Greenwich meridian and Vernal Equinox at \( t_i \)

\( \Theta_e \) East longitude of the tracking station (radian)

P1-5
Euler angle specifying the opening angle of precession about angular momentum vector L (Ref. P1, P4, Fig. 2.5)

θ
Angle between the directional counter symmetry axis and the plane perpendicular to the magnetic flux density B; 
θ = π/2 - α (deg); \( \lambda = \pi/2 - \delta \)

θ'
Angle between directional flux density vector J and the plane perpendicular to the magnetic flux density vector B (deg)

θ_s
East longitude of satellite from Vernal Equinox (radian)

\( \lambda_g \)
Geographic latitude (radian)

\( \lambda_g^* \)
Conjugate geographic latitude (radian)

\( \lambda_{gm} \)
Geomagnetic latitude (radian)

μ
Magnetic dipole moment

τ
Time parameter

\( \tau_{i'} \)
G-M counter deionization (deadtime) (sec)

\( \tau_d \)
Scintillation counter deadtime

ν
Whistler frequency (Ref. P3, Eq. (4.13))

\( \nu_c \)
Cyclotron frequency (Ref. P3, Eq. (4.2))

\( \nu_A \)
Hm wave frequency (Ref. P3, Eq. (4.2))

ϕ
Flux invariant (Ref. P3, Eq. (3.28))

\( \phi \)
Euler angle measured in X-Y plane

\( \phi' \)
Precession rate about angular momentum vector L (rad sec\(^{-1}\))

ψ
Euler angle in the plane of rotation about Z'-axis from the line of nodes to the rotating satellite fixed X'-axis (deg)

\( \psi(\theta') \)
Element of an orthonormal set

\( \psi' \)
Residual angular velocity about Z'-axis after transition to propeller-like configuration (rad sec\(^{-1}\))

\( \omega_p \)
Plasma frequency (Ref. P3, Eq. (3.28))

\( \omega_c \)
Joppler shifted whistler frequency (Ref. P3, Eq. (4.7))

\( \omega_z' \)
Angular velocity about Z'-axis (rad sec\(^{-1}\))

\( \omega_{z0} \)
Initial angular velocity about the Z'-axis at orbit insertion (rad sec\(^{-1}\))
References:

P1. "Van Allen Radiation Belt and ARGUS Directional Flux Density Distributions, Explorer 4 Satellite Data", Ph.D. Dissertation, D. J. Manson, February 1967, Saint Louis University, St. Louis, Missouri

P2. "Interpretation of Directional Flux Densities in ARGUS Shells, Explorer 4 Satellite Data", Ph.D. Dissertation, J. M. Paikeday, June 1966, Saint Louis University, St. Louis, Missouri

P3. "Omnidirectional Fluxes; Explorer 4 Satellite Data, ARGUS Events 1 and 2", Ph.D. Dissertation, J. A. George, February 1967, Saint Louis University, St. Louis, Missouri

P4. "Analysis of ARGUS/Explorer 4 Records", DASA 1613, January 1965, Saint Louis University, Physics Department, St. Louis, Missouri
Table P2-1. Instrumentation calibration information, Explorer 4

<table>
<thead>
<tr>
<th>Detectors</th>
<th>Channel</th>
<th>Deadtime (sec)</th>
<th>Effective Shielding (gm·cm⁻²)</th>
<th>Particles (e, electrons; p, protons; γ, photons)</th>
<th>Saturation Counts (sec⁻¹)</th>
<th>Geometric Factors G₀ (cm²)</th>
<th>Counter efficiency x effective area, εₐ eff A (cm²); 1/εₐ eff = G₀/G₀</th>
</tr>
</thead>
<tbody>
<tr>
<td>Detector A, Plastic Scintillation</td>
<td>2, 5</td>
<td>91 x 10⁻⁶; Van Allen (7); 112 x 10⁻⁶; Baicy (2); 100 x 10⁻⁶; SLU (3)</td>
<td>0.14 Al, of window, Van Allen (1)</td>
<td>Eₑ &gt; 0.58 MeV, Van Allen (1); Eₚ &gt; 0.7 MeV, Baicy (2); Eₐ &gt; 10 MeV, Van Allen (1)</td>
<td>10 x 10³ from max observed count-rates, SLU (3)</td>
<td>Response function S(α) Baicy (2)</td>
<td>0.0026, Baicy-Bock (6); 6.29 x 10⁻⁴ for photons, Baicy (2)</td>
</tr>
<tr>
<td>Detector C, Anton 302 0-M counter; unshielded</td>
<td>3</td>
<td>62.5 x 10⁻⁶ from max observed count-rates, SLU (3)</td>
<td>1.2 stainless steel (satellite shell), Van Allen (1) (=1.6 Al, SLU (4))</td>
<td>Eₑ &gt; 3 MeV, Eₚ &gt; 30 MeV, Eₐ &gt; 40 MeV, Van Allen (1)</td>
<td>2000 photons, Baicy (2); 5800 electrons from max observed count-rates, SLU (3)</td>
<td>G₀ = 0.60 for fission electrons, SLU (4); G₀ = 0.37 for protons in natural region, SLU using McIlwain (5)</td>
<td>0.015 for fission electrons, SLU (4); 0.32 for protons in natural region, SLU using McIlwain (5)</td>
</tr>
<tr>
<td>Detector D, Anton 302 0-M counter; shielded</td>
<td>1</td>
<td>62.5 x 10⁻⁶ assumed, same as Detector C</td>
<td>1.2 stainless steel +1.6 lead, Van Allen (1); (=3.88 Al, SLU (4))</td>
<td>Eₑ &gt; 5 MeV, Eₚ &gt; 40 MeV, Van Allen (1)</td>
<td>None</td>
<td>G₀ = 0.48 for protons in natural region, SLU using McIlwain (5)</td>
<td>0.41 for protons in natural region, SLU using McIlwain (5)</td>
</tr>
</tbody>
</table>

Eₑ, electron energy
Eₚ, proton energy
Eₐ, photon energy
Fig. P2-1. Block diagram, Explorer 4 instrumentation and telemetry


P2-3. 'Analysis of ARGUS/Explorer IV Records", DASA WT-1613, Saint Louis University, Physics Department, St. Louis, Missouri, (January, 1965).

P2-4. George, John A., "Omnidirectional Fluxes; Explorer 4 Satellite Data, ARGUS Events 1 and 2", Ph.D. Dissertation, Physics Department, Saint Louis University, St. Louis, Missouri (1967).


A. Summary of Pn.D. Dissertation, Donald J. Manson, "Van Allen Radiation Belt and ARGUS Directional Flux Density Distributions, Explorer 4, Satellite Data"; Saint Louis University, Physics Department (February 1967).

A1. Introduction

A recent determination (Ref. A1) of the correct roll (or spin) rate for satellite Explorer 4 has allowed, for the first time, systematic and reliable determinations of directional flux density distributions of geomagnetically trapped charged particles injected by the ARGUS Event 1 of 27 August 1958. The results of the present analysis (1) indicate a pronounced and unique omnidirectional penetrating radiation effect associated only with ARGUS Event 1, (2) include a comparison of directional flux density distributions (particles cm\(^{-2}\)sec\(^{-1}\)ster\(^{-1}\)) of the naturally (inner Van Allen Belt) and artificially (ARGUS Event 1) injected radiation, and (3) permit determination of a decay curve for a limited time period of the measured maximum (perpendicular to \(\vec{B}\)) directional particle flux density of the artificially injected (ARGUS Event 1) radiation.

A2. Analysis and Experimental Details

The angle \(\theta\) between the directional (scintillation Detector A, Channel 2,5) counter and a plane perpendicular to the magnetic flux density vector \(\vec{B}\) is determined as a function of time by calculating the rotational (roll and tumble motion) and forward motions of the satellite, the Vernal Equinox coordinate system. Critical phase angles for the roll and tumble motions at an initial reference time A1
are determined by analysis of the r-f electric field strength patterns from the telemetry and by "loop closure-search" (based on the assumption that at equal angles of the counter axis relative to \( \mathbf{B} \) the counting rates are equal; see Ref. A2 for details). Each short time-period section of count-rate data between signal fadeouts (corresponding to one-half a tumble cycle) is analysed separately. Satellite telemetry yields primarily count-rates versus time (Ref. A2) which, combined with the calculation of \( \theta \) as a function of time, yields observed count-rate \( C_{\text{obs}} \) as a function of \( \theta \). Correcting for deadtime, counter efficiency and effective area (Ref. A2), and solving the integral equation (Ref. A3) relating count-rate to the directional flux and the counter response function, yields by an unfolding procedure the directional flux density \( J(\theta') \) (particles cm\(^{-2}\)sec\(^{-1}\)ster\(^{-1}\)). With the aid of the magnetic mirror condition \( J_{\text{max}}(\theta') \), (\( \theta' \), angle between vector \( \mathbf{J} \) and a plane perpendicular to \( \mathbf{B} \)), the directional particle flux density perpendicular to \( \mathbf{B} \) is then calculated for larger values of \( B \) of the L shell on which the \( J(\theta') \) vs \( \theta' \) distribution data was acquired by Explorer 4.

Figure A1 demonstrates the validity of the method used to calculate \( \theta \) as a function of time by indicating the consistency of all the data acquired by the directional counter for 4 minutes of trajectory in the Natural region of radiation (\( L = 1.35-1.44 \); approximately 1200 miles of satellite trajectory). It is evident that much of the observed scatter is due to decrease in the maximum count-rate as the satellite moves to increased values of \( B \) and \( L \), and that the shape of the count-rate vs \( \theta \) distribution is sensibly constant with small variations of \( L \) for the Natural radiation in this region. The relatively constant counting rate for large values of \( \theta \) indicates a penetrating component of the radiation.
A3. Results

All the data acquired from the unshielded G-M counter (Detector C, Channel 3) and the directional scintillator (Detector A, Channel 2) for Passes 414 and 427 are summarized in Figs. A2 (Upper and Lower). Triangle-points for each of the two Figures are count-rate maxima (counter axis perpendicular to \( \mathbf{B} \)) determined from directional distributions such as shown by Fig. A1, dot-points are in turn the minima (counter axis parallel to \( \mathbf{B} \)); the dashes are the average count-rate from the unshielded G-M counter (detects electrons of energy greater than 3 MeV; protons, greater than 31 MeV) and the X-points are the average count-rates from the shielded (Detector D, Channel 1) omnidirectional G-M counter (detects electrons of energy greater than 6 MeV; protons, greater than 40 MeV). Decrease in maximum count-rate with increasing B and L (Fig. A2) is evident for the Natural radiation (to the "left" of the arrows along the time axes); clearly visible is ARGUS Event 1 at \( L = 1.62 - 1.76 \). For Pass 414 a core of penetrating radiation is indicated (between arrows along time axes) at \( L = 1.71 \) to 1.76, 1.8 hrs following the nuclear event; this directional penetrating component is not observed 24 hrs later (Pass 427). Comparison of Passes 414 and 427 indicates essential constancy of the Natural radiation but rapid decay of the ARGUS shell within a 24-hour period, and also indicates a change in energy distribution suggested by a difference in ratios (of the penetrating component of the directional scintillator count-rates to the average count-rates of the omnidirectional unshielded G-M counter) for the same 24-hour period.

Figure A3 indicates a comparison of the directional flux density distribution, \( J(\theta') \) vs \( \theta' \); for the Natural (left-hand plot), and the ARGUS Event 1 radiation (right-hand plot) of 28 August 1958, 25.48 hrs following the event.
This section contains a revised (relative to our Final Report, DASA Report 1613, 15 January 1965) interpretation of the penetrating radiations observed during Pass 414 (over Huntsville) of Explorer 4. Hence Figs. A4, 5, 6 from Report 1613 are reproduced in the present section.

Figures A4, A5, and A6 are the result of detailed directional analysis of the data acquired from the region indicated by the arrows on time axis (Fig. A2, Upper) where the penetrating radiation mentioned in A3 above was observed. The method of treating each limited portion of telemetry data between signal fadeouts allows plotting of the count-rate, vs time and \( \theta \), during each fractional part of a rotation of the scintillator counter axis with respect to \( \mathbf{B} \). As indicated by Fig. A1 this method yields a consistent disk-like shape for the Natural radiation with all data clustering around one curve.

Figures A4, A5, and A6 indicate considerable departure of the ARGUS Event 1 radiation, 1.8 hrs after the event, from the disk-like shape of the Natural radiation and so each partial rotation of the counter axis with respect to \( \mathbf{B} \) has been plotted separately except for Fig. A4 (b,c,d) where three such rotations (from the early penetration of the ARGUS shell have been superimposed to yield a count-rate vs \( \theta \) distribution much like that for the Natural radiation).

In Fig. A4(f) the time sequence shown by the arrows indicates that the average count-rate is increasing rapidly during one partial rotation (approx. 3.6 secs) so that at equal angles of the counter axis with respect to \( \mathbf{B} \) (e.g., \( \theta \approx 60 \text{ deg} \)) two different count-rates
are observed, the later count-rate having increased as the satellite
penetrated farther into the ARGUS shell. It should be noted that
the omnidirectional penetrating component (at large $\theta$ values) has
increased rapidly (from 2000 counts sec$^{-1}$ in Fig. A4(b,c,d) to approxi-
mately 5000 counts sec$^{-1}$ in Fig. A4(f)). The large count-rate (9000
sec$^{-1}$, $\theta = 52$ deg, Fig. A4(f)), at larger angles of $\theta$ indicates a
departure from the disk-like shape of the radiation. Figure A4(g)
indicates that the scintillation counter is saturating (count-rate,
greater than 10,000 sec$^{-1}$) when perpendicular to $\mathbf{E}$ ($\theta = 0$) while the
count-rate at $\theta = 50$ deg has dropped (from 9000 to 7000 sec$^{-1}$).
Figure A4(h) indicates saturation at small to moderate $\theta$ angles
($\geq 10,000$ sec$^{-1}$, $\theta \leq 40$ deg) and a count-rate of almost 7000 sec$^{-1}$
at $\theta = 60$ degrees — again a considerable departure from disk-like
shape of the count-rate vs $\theta$ distribution.

Figure A5(j) (acquired 2.5 secs later than Fig. A4(h)) indicates
a more normal disk-like shape but for a limited range around $\theta = 0$.
Figures A5(j,k,l and m) if superimposed would yield a single consistent
distribution much like Fig. A5(m) where the $C_{\text{obs}}$ vs $\theta$ distribution is
disk-like ($\theta \leq 30$ deg) but with a large omnidirectional penetrating
background component ($\geq 5000$ sec$^{-1}$). The final 5 points of the time
sequence (arrows) shown in Fig. A5(m) indicate a sudden saturation of
the counter ($\theta \leq 30$ deg).

This saturation is continued in Fig. A6(n) at $\theta = 30$-35 degrees
but is followed in Figs. A6(o) by an abrupt change to a more nearly
disk-like distribution; followed immediately in turn by saturation for
all angles $\theta \leq 40$ deg. Figure A6(p) (0.2 sec later) indicates a
return to the normal disk-like shape followed by a sharp drop in the
count-rate at $\theta = 0$ as the satellite leaves the ARGUS shell. Figure A4(q) is for the last measurable count-rates from the ARGUS Event 1 wing as the satellite moves into the slot between the two Van Allen belts away from the ARGUS shell.

The analysis presented relative to Figs. A4, 5, 6 suggests that the data from Pass 414, 1.8 hrs after Event 1 contains evidence for short term penetrating components (directional and omnidirectional) of the radiation which are neither spatially homogenous nor isotropic. The fact that the scintillation counter goes to saturation suddenly during one portion of the rotation of the counter axis with respect to vector B as in Fig. A5(m) and A6(o) while the remaining portion of the rotation measures a fairly normal distribution suggests a varying directional component of the flux at these points (possibly due to gamma radiation from trapped debris near the ARGUS shell). The normal disk-like distributions (Fig. A3) measured in the ARGUS shell 1 day later for Pass 427 apparently are present in Pass 414 but are obscured and distorted by the large penetrating omnidirectional component and bursts of directional radiation which saturate the counter. These effects are greatly diminished in Pass 415, (3.67 hrs following Event 1) and are not found in Pass 427 (25.48 hrs following Event 1).

No such effects were found from ARGUS Event 2 where data from Pass 454 (1.87 hrs following Event 2, 30 August 1958; Refs. A2, A4) indicate the usual disk-like distributions.

Figure A7 indicates the time decay of maximum directional flux density $J_{\max}(\theta')$ for two days following ARGUS Event 1. It was not possible to follow the decay for a longer period than two days because by the third day the directional trapped radiation intensity has diminished to near background value.
The x-points lie well on a straight line (exponential decay law), the solid-line curve is a plot of the $t^{-1.13}$ law (observed for the omnidirectional radiation, see Part C of the present report) for comparison. Because of the short time interval represented, about 2 days, a decision between the two decay laws is not considered valid.

Figure A8 is a 3-dimensional plot of $J_{\text{max}}(\theta')$, the directional flux density perpendicular to $\hat{B}$, vs $B$ and $L$; both Natural and ARGUS Events 1 and 2 radiations are shown. Figure A8 summarizes most of the data analysed for the scintillation counter, Detector A.

A5. Conclusions

Detailed analysis of ARGUS directional flux density distributions from Explorer 4 data (Passes 414 and 427, over Huntsville, Alabama, on 27 and 28 August 1958 respectively) for 1.8 and 25.48 hrs respectively after Event 1 and comparison with Natural flux density distributions indicate that the disk-like shape as measured by the scintillation counter in the ARGUS shell is not substantially different from the Natural radiation (by Fig. A3, the half-width at half-maximum (hwhm) is 7 deg broader on the average for the ARGUS $J(\theta')$ compared to the Natural radiation; maximum values of directional flux densities are $12 \times 10^7$ for the Natural vs $6.7 \times 10^7$ cm$^{-2}$sec$^{-1}$ster$^{-1}$ for ARGUS). The 27 August 1958 data from Pass 414 (Ref. A2) and Pass 415 (Ref. A3) indicate that these measured distributions are temporarily obscured and distorted by a large penetrating omnidirectional component and a varying directional component. The short-time limited decay data suggest an exponential decay of maximum directional flux density at $L = 1.7$ but a $t^{-1.13}$ law observed for the omnidirectional data from
G-M counter (Detector C) is not excluded. It may be suggested that particle and energy differences between Natural and ARGUS radiations can be expected to yield somewhat different decay laws.

A6. References
A2. "Van Allen Radiation Belt and ARGUS Directional Flux Density Distributions, Explorer 4 Satellite Data", Ph.D. Dissertation, D. J. Manson, Saint Louis University, Physics Department, 1 July 1966.
Fig. A1. Pass 427 (over Huntsville, Alabama, 28 August 1958) observed directional count-rate $C_{\text{obs}}$ vs $\theta$ for 4 min in the region of Natural radiation.

$C_{\text{obs}}$ vs $\theta$; 227.5 - 229.5 min UT; L, 1.35 - 1.42 earth radii; B, 0.145 - 0.164 gauss; $A$, $C_{\text{obs}}$ vs $\theta$; 229.5 - 231.5 min UT; L, 1.42 - 1.49 earth radii; B, 0.164 - 0.180 gauss.

Data were plotted by combining about one-half of the 100 individual sections of $C_{\text{obs}}$ vs $\theta$ described in Ref. A2, Sec. 3.3. All data acquired within the time period 227.5 - 231.5 UT are plotted to show the amount of scatter in the data and to demonstrate the consistency of the analytic interpretation using the experimentally determined parameters: roll and tumble phase angles $\delta$ and $\gamma$, and the roll and tumble rates.
PASS 427 NATURAL
227.5 - 231.5 UT (min)
AUGUST 28, 1958

THETA (deg)

Counts/sec

9x10^3

6

3

0
Fig. A2. (Upper, Lower)

Natural and ARGUS Event 1 count-rates vs time and 
B-L coordinates for Passes 414 and 427 over Huntsville, 
Alabama. Comparison of Average Omnidirectional Count-
Rate with Maximum (perpendicular to $\vec{B}$) and Minimum 
(parallel to $\vec{B}$) Directional Counting Rates.

Triangle-points, maxima; and dot-points, minima, 
scentillation counter (Detector A) observed count-rates; 
Dash-points, 15-sec averages of observed omnidirectional 
(unshielded G-M counter, Detector C) count-rates; 
X-points, 6-sec averages of observed omnidirectional 
count-rates (shielded G-M counter, Detector D).

Arrows on the time axis indicate time region in which 
distributions of Figs. A4, 5, and 6 (Pass 414) were acquired 
(ARGUS Event 1). Calibration information for the three 
counters is summarized in the Preface (P1) of the present 
report.
Fig. A3. Directional flux density distributions $J(\theta')$ vs $\theta$

for Pass 427, 28 August 1958; Natural (left-hand plot) and ARGUS Event 1 (right-hand plot) radiations.

Variations of magnitudes of $J_{\text{max}}(\theta') = J(0)$ and shape of the distributions are shown. $J(\theta')$ for ARGUS Event 1 radiation were corrected for varying penetrating radiation component as explained in Ref. A2.
PASS 427 NATURAL

<table>
<thead>
<tr>
<th>TIME (min UT)</th>
<th>J(0) (cm$^2$sec$^{-1}$ster$^{-1}$)</th>
<th>hwhm (deg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a) 227.5-229.0</td>
<td>12x10$^7$</td>
<td>16</td>
</tr>
<tr>
<td>(b) 231.0-232.0</td>
<td>6.5x10$^7$</td>
<td>20</td>
</tr>
<tr>
<td>(c) 234.0-235.0</td>
<td>2.7x10$^7$</td>
<td>15</td>
</tr>
</tbody>
</table>

L (earth radii) | B (gauss) |
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>(a) 1.355-3.77</td>
<td>0.145-0.153</td>
</tr>
<tr>
<td>(b) 1.431-4.65</td>
<td>0.167-0.175</td>
</tr>
<tr>
<td>(c) 1.555-6.10</td>
<td>0.192-0.202</td>
</tr>
</tbody>
</table>

PASS 427 ARGUS EVENT 1

<table>
<thead>
<tr>
<th>TIME (min UT)</th>
<th>J(0) (cm$^2$sec$^{-1}$ster$^{-1}$)</th>
<th>hwhm (deg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a) 236.0-236.5</td>
<td>1.6x10$^7$</td>
<td>19</td>
</tr>
<tr>
<td>(b) 236.6-236.68</td>
<td>2.5x10$^7$</td>
<td>27</td>
</tr>
<tr>
<td>(c) 236.69-236.85</td>
<td>6.75x10$^7$</td>
<td>21</td>
</tr>
<tr>
<td>(d) 236.87-237.0</td>
<td>16x10$^7$</td>
<td>22</td>
</tr>
<tr>
<td>(e) 237.0-237.62</td>
<td>13x10$^7$</td>
<td>24</td>
</tr>
</tbody>
</table>

L (earth radii) | B (gauss) |
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>(a) 1.675-7.10</td>
<td>0.215-2.74</td>
</tr>
<tr>
<td>(b) 1.710-7.38</td>
<td>0.217-2.94</td>
</tr>
<tr>
<td>(c) 1.739-7.47</td>
<td>0.295-2.216</td>
</tr>
<tr>
<td>(d) 1.740-7.57</td>
<td>0.2200-2.224</td>
</tr>
<tr>
<td>(e) 1.757-7.98</td>
<td>0.2224-2.300</td>
</tr>
</tbody>
</table>
Figs. A4, A5, and A6

Detailed sequence of scintillation counter count-rates $C_{\text{obs}}$ vs $\theta$ (angle between scintillation counter axis and the plane perpendicular to $\mathbf{B}$) for Pass 414 ARGUS Event 1 penetration, 27 August 1958. Where used arrows indicate time sequence in acquisition of points. Distributions indicate a large omnidirectional penetrating component and a varying directional component of the radiation (discussed in detail in the text).
ARGUS EVENT I

(b,c,d) 256.083 - 256.209 UT (min)
PASS 414 ARGUS
27 AUGUST 1958

(f) 256.318 - 256.378 UT (min)
PASS 414 ARGUS
27 AUGUST 1958

(g) 256.381 - 256.416 UT (min)
PASS 414 ARGUS
27 AUGUST 1958

(h) 256.420 - 256.496 UT (min)
PASS 414 ARGUS
27 AUGUST 1958
ARGUS EVENT 1

(j) + 256.538 - 256.599
UT (min)
PASS 414 ARGUS
27 AUGUST 1958

(k) + 256.601 - 256.653
UT (min)
PASS 414 ARGUS
27 AUGUST 1958

(l) 256.662 - 256.711
UT (min)
PASS 414 ARGUS
27 AUGUST 1958

(m) 256.722 - 256.756
UT (min)
PASS 414 ARGUS
27 AUGUST 1958
Fig. A7. Decay of maximum directional particle flux densities $J_{\text{max}}(\theta')$ vs time for ARGUS Event 1. Plotted points are for flux density distributions $J(\theta)$ at $\theta' = 0$. The maximum ARGUS Event 1 radiation is observed to decay one order of magnitude in 45 hrs. The lower curve is a plot of the $t^{-1.13}$ law (observed for the omnidirectional radiation, Part C of the present report, for the same ARGUS Event 1 radiation).
DECAY OF MAXIMUM OMNIDIRECTIONAL FLUX DENSITY FROM ARGUS EVENT 1
27-29 AUGUST 1958
L = 1.7

\[ J_{\text{MAX}}(\theta) (\text{cm}^{-2} \text{sec}^{-1} \text{ster}^{-1}) \]

\[ \times \text{ OBSERVED DECAY} \]

\[ t^{-1.128} \text{ DECAY} \]
Fig. A8. Directional maximum particle flux density \( J_{\text{max}}(\theta') \) vs \( \theta \) and \( L \) for both Natural and ARGUS Events 1 and 2 radiations (Detector A, Channel 2)

Detailed information is tabulated as follows.

### Natural Radiation

<table>
<thead>
<tr>
<th>( L ) (earth radii)</th>
<th>Slope</th>
<th>Pass No.</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \alpha )</td>
<td>1.360</td>
<td>-7.92</td>
<td>427</td>
</tr>
<tr>
<td>( \beta )</td>
<td>1.360</td>
<td>-7.92</td>
<td>414</td>
</tr>
<tr>
<td>( \gamma )</td>
<td>1.360</td>
<td>-7.15</td>
<td>414</td>
</tr>
<tr>
<td>( \delta )</td>
<td>1.360</td>
<td>-7.15</td>
<td>454</td>
</tr>
<tr>
<td>( \epsilon )</td>
<td>1.360</td>
<td>-7.15</td>
<td>454</td>
</tr>
<tr>
<td>( \eta )</td>
<td>1.360</td>
<td>-7.15</td>
<td>427</td>
</tr>
<tr>
<td>( \zeta )</td>
<td>1.360</td>
<td>-7.15</td>
<td>427</td>
</tr>
</tbody>
</table>

### ARGUS EVENT 1

| \( \theta \)          | 1.690 | -3.78    | 414           | 27 Aug. 1958 |
| \( \zeta \)           | 1.694 | -6.42    | 427           | 28 Aug. 1958 |
| \( \lambda \)         | 1.724 | -4.10    | 427           | 28 Aug. 1958 |
| \( \mu \)             | 1.728 | -4.11    | 440           | 29 Aug. 1958 |
| \( \nu \)             | 1.730 | -3.58    | 415           | 27 Aug. 1958 |
| \( \xi \)             | 1.743 | -5.05    | 427           | 28 Aug. 1958 |
| \( \omega \)          | 1.748 | -2.00    | 427           | 28 Aug. 1958 |
| \( \lambda \)         | 1.777 | -4.48    | 427           | 28 Aug. 1958 |

### ARGUS EVENT 2

| \( \pi \)             | 2.124 | -7.55    | 454           | 30 Aug. 1958 |
| \( \rho \)            | 2.124 | -3.60    | 454           | 30 Aug. 1958 |
| \( \sigma \)          | 2.144 | -15.40   | 454           | 30 Aug. 1958 |
| \( \tau \)            | 2.172 | -10.40   | 454           | 30 Aug. 1958 |
B. Summary of M.S. Thesis of Joseph P. Fennell, "Van Allen Belt and ARGUS Directional Flux Density Distributions, Explorer 4 Satellite Data, ARGUS Event 2", Saint Louis University, Physics Department (July 1966).

B1. Introduction

This Thesis, Reference B1, contains essentially an analysis of the directional distribution of flux densities (particles cm$^{-2}$ sec$^{-1}$ ster$^{-1}$) vs the angle between the counter symmetry axis and the plane perpendicular to the magnetic flux density vector, of geomagnetically trapped naturally occurring and artificially injected charged particles associated with ARGUS Event 2 for Pass 454 over Huntsville, Alabama (for a time interval of about 10 min. beginning 1.8 hrs following the Event). The purpose of this limited analysis was to compare the situation with that of Pass 414 (Manson Dissertation, Ref. B2) with the Passes occurring approximately 3 days apart. The count-rate data were obtained from a scintillation photomultiplier detector (Detector A, Channel 2 Ref. B2); window aperture, 15 degrees half-width at half-maximum; $A_{\text{eff}}$, 0.026 cm$^2$; deadtime 100 microsecs aboard Satellite Explorer 4.

The thesis represents the first detailed examination of the directional data for ARGUS Event 2 by the Saint Louis University group. There is presented a short discussion of a method for determining the proper roll phase angle used in this analysis and the results from determinations of satellite roll frequencies for times at which they had not been previously determined with sufficient precision to yield reliable determinations of observed count-rate $C_{\text{obs}}(\theta)$ vs angle $\theta$ (between the counter symmetry axis and a plane perpendicular to the magnetic flux density vector B).
B2. Determination of the Phase Angle for the Roll Motion of Satellite

To determine the directional flux density $J(\theta')$ vs angle $\theta'$ between the counter axis and the incident flux direction, $C_{\text{obs}}(\theta)$ as a function of $\theta$ must be known. $\theta$ at time $t$ (relative to an arbitrary reference time) is given by

$$\theta = \arcsin \left[ b_1 \sin(\dot{\psi} t + \delta) - b_2 \cos(\dot{\psi} t + \delta) \sin(\dot{\phi} t + \gamma) \right] + b_3 \cos(\dot{\psi} t + \delta) \cos(\dot{\phi} t + \gamma) \right], \quad (B1)$$

where all parameters are known explicitly except $\delta$ and $\gamma$, the roll and tumble motion phase angles. $\gamma$ was determined as

$$\gamma = \arccos (\hat{A} \cdot \hat{y}_s), \quad (B2)$$

where $A$ is the satellite symmetry axis vector and $y_s$ is a unit vector in Vernal Equinox Coordinates (Ref. B2).

$\delta$ is determined (Ref. B1) in Eq. (B1) by assuming counting rates are equal approximately at equal angles $\theta$ in the Natural radiation region (over short periods of time, $t \leq 0.5$ min). Taking two times $t_1$, $t_2$ with equal counting rates, it can be shown (Ref. B1) from Eq. (B1) that

$$\delta_{ij} = \arctan \left( -f_{ij} / g_{ij} \right) \quad (B3)$$

where $f_{ij} = f_1 + f_2, g_{ij} = g_1 + g_2, f_1 = b_1(t_1) \sin(\dot{\psi} t_1) + P(t_1, \gamma) \cos(\dot{\psi} t_1), g_1 = b_1(t_1) \cos(\dot{\psi} t_1) - P(t_1, \gamma) \sin(\dot{\psi} t_1)$ and $P(t_1, \gamma) = b_2(t_1) \cos(\dot{\phi} t_1 + \gamma) - b_3(t_1) \sin(\dot{\phi} t_1 + \gamma)$. 

B2
An average $\delta$ is then determined by considering
\[ \delta_{\text{avg}} = \arctan \left( -\frac{\sum (f_{ij} \times g_{ij})}{N} \right) \]  
\hspace{1cm} (B4)

where the sum is over $N$ time pairs $t_i$, $t_j$. The consistency of the data can be seen by considering the variations in the $\delta_{ij}$ from $\delta_{\text{avg}}$. If the spread in the values of $\delta_{ij}$ is small the random fluctuations in the data are small. $\delta_{\text{avg}}$ was determined (with respect to an arbitrary reference time) as $90^\circ$ for Pass 454 and this value reproduced the count-rate variations in a simulator program (see Ref. B2).

The roll rate for Explorer 4 was determined for the entire telemetry times of Passes 414 through 454 by fitting a least square polynomial to the known roll rate values at discrete reference times of Passes 414, 415, 427, and 454. A second method for determining the roll rate, based on the fact that $\sin \theta$ is a minimum when $C_{\text{obs}}(\theta)$ is maximum is presented by Fennell (Ref. B1). (The second method was applied to Pass 440 and the resulting roll rate was used by J. M. Paikeday (Ref. B3) to obtain a directional flux density distribution for Pass 440 ARGUS Event 1 radiation.)

B3. Results

With $\theta$ determined as a function of time, plots $C_{\text{obs}}(\theta)$ vs $\theta$ are made and then corrected for the counter deadtime and (effective area x counter efficiency) to yield the true count-rate $C(\theta)$
\[ C(\theta) = \frac{C_{\text{obs}}(\theta)}{\epsilon A_{\text{eff}} (1 - T_B \frac{C_{\text{obs}}(\theta)}{})}. \]  
\hspace{1cm} (B5)
The corrected or true count-rates $C(\theta)$ are used to compute the corresponding directional flux densities $J(\theta')$ as described by J. M. Paikeday (Ref. B3). Representative examples of the observed count-rates $C_{obs}(\theta)$ vs $\theta$, true count-rates $C(\theta)$ vs $\theta$, and directional flux densities $J(\theta')$ vs $\theta'$ for Pass 454 Natural radiation are shown by Figs. B1 and B2. The $C_{obs}(\theta)$ vs $\theta$ curves showed an "open loop" phenomena (see Fig. B3(a)) which is due in part to the rapid rate of change of both the omnidirectional and directional components of the radiation as the satellite moves through the ARGUS Event 2 shell. The curve was reduced to a single valued curve by subtracting out this component (compare Fig. B3(a) and $C_{obs}(\theta)$ of Fig. B3(c)). The resulting $C_{obs}(\theta)$ vs $\theta$, $C(\theta)$ and $J(\theta')$ vs $\theta$, $\theta'$ curves for the ARGUS radiation are shown in Figs. B3, B4. Figures B1, 2, 3, 4 and Tables B1, B2 in the Figs. B2, B4 captions represent the results of this analysis.

B4. Conclusions

The maximum directional flux density and observed count-rate vary considerably in the six minutes of the Natural radiation observed for Pass 454 while the half-width at half-maximum (hwhm) remains relatively constant at $17 \pm 5$ degrees (see Table B1, Fig. B2 caption). The variation in maximum count-rate and flux density is probably related to the large spatial and magnetic flux density changes involved in the satellite motion.

The non-zero $J(\theta')$ for $\theta' \geq 50$ to 60 degrees (Fig. B2), in the Natural radiation region is due probably to penetrating (independent of $\theta'$) radiation capable of transmission by the counter shielding ($E_\parallel \lesssim 3$ Mev); it is the background count-rate for the detector in the region of Natural radiation.
The flux densities and hwhm vary considerably for the ARGUS Event 2 Pass 454 radiation. By Fig. B4 the ARGUS radiation appears generally to have a smaller hwhm \((16^\circ \text{ vs } 18^\circ)\) and a larger maximum flux density \((6.4 \times 10^7 \text{ vs } 4.9 \times 10^7 \text{ particles cm}^{-2}\text{sec}^{-1}\text{ster}^{-1})\) than the Pass 454 Natural radiation. It is noted that there are large differences in B and L coordinates between the Natural and ARGUS radiations. The results for Pass 454 are included in Table B2 for comparison with previous analysis (Refs. B2, B3, B4, B5).

The maximum flux intensity and hwhm of the Pass 454 ARGUS Event 2 are considerably lower \((6.4 \times 10^7 \text{ vs } 2.3 \times 10^8 \text{ particles cm}^{-2}\text{sec}^{-1}\text{ster}^{-1})\) and narrower \((16^\circ \text{ vs } 24^\circ)\) respectively than those of Pass 414 for ARGUS Event 1 with both Passes occurring about 1.8 hours after their respective events. Assuming both nuclear devices were the same, the differences in Pass 414 and Pass 454 ARGUS results may be due to spatial or geomagnetic effects. The data occurred at the two L's, 1.72 (Event 1) and 2.1 (Event 2).

Some tentative conclusions can be offered for Pass 454 Event 2, as follows:

1) ARGUS radiation is more intense than the Natural as is evidenced from the Tables B1 and B2 (see Figs. B1, B4 captions).

2) ARGUS radiation appears to be slightly more disk-like than Natural as is evidenced from the hwhm (Tables B1, B2, B3).

3) ARGUS radiation showed no sign of any rapidly varying omnidirectional penetrating radiation effect as was observed by Manson (Ref. B2) in Pass 414.
Since Pass 454 is the only ARGUS Event 2 directional data which has been analyzed by the methods presented in Refs. B1 and B2 to date, a more intensive study of Event 2 data and a more complete comparison with Event 1 directional data must await the analysis of more Event 2 directional data.

B5. References


Fig. Bl. Representative $C_{\text{obs}}(\theta)$ vs $\theta$ curves for Pass 454 Natural radiation. Actual data points are shown to indicate the scatter in $C_{\text{obs}}(\theta)$ vs $\theta$. 
Fig. B2. True count-rate $C(\theta)$ (counts cm$^{-2}$sec$^{-1}$ corrected for deadtime, effective area and counter efficiency) and directional flux $J(\theta')$ (particles cm$^{-2}$sec$^{-1}$ster$^{-1}$) vs $\theta$ and $\theta'$ for the Fig. B1 $C_{\text{obs}}(\theta)$ curves. The bars on the $J(\theta')$ vs $\theta'$ curves indicate the scatter in calculated values of $J(\theta')$ due in turn to the scatter of points in the corresponding $C_{\text{obs}}(\theta)$ vs $\theta$ curves.

Table B1. Characteristics of Natural radiation (from Ref. B1)

<table>
<thead>
<tr>
<th>Time (min)</th>
<th>*hwhm (deg)</th>
<th>$J(\theta')_{\text{max}}$</th>
<th>B (gauss)</th>
<th>L(earth radii)</th>
</tr>
</thead>
<tbody>
<tr>
<td>300.00</td>
<td>22.0</td>
<td>$4.9 \times 10^7$</td>
<td>1.734</td>
<td>1.376</td>
</tr>
<tr>
<td>301.221</td>
<td>17.5</td>
<td>$4.9 \times 10^7$</td>
<td>1.782</td>
<td>1.414</td>
</tr>
<tr>
<td>301.915</td>
<td>17.5</td>
<td>$4.7 \times 10^7$</td>
<td>1.806</td>
<td>1.434</td>
</tr>
<tr>
<td>302.370</td>
<td>17.5</td>
<td>$3.5 \times 10^7$</td>
<td>1.834</td>
<td>1.458</td>
</tr>
<tr>
<td>304.570</td>
<td>16.0</td>
<td>$1.4 \times 10^7$</td>
<td>1.912</td>
<td>1.583</td>
</tr>
<tr>
<td>305.725</td>
<td>16.0</td>
<td>$8.2 \times 10^6$</td>
<td>2.172</td>
<td>1.640</td>
</tr>
<tr>
<td>306.990</td>
<td>12.0</td>
<td>$7.7 \times 10^5$</td>
<td>2.316</td>
<td>1.776</td>
</tr>
</tbody>
</table>

* half-width at half-maximum
Fig. B3.

(a) $C_{\text{obs}}(\theta)$ vs $\theta$ ARGUS Event 2 'loop' before the linearly increasing background has been subtracted. Compare Fig. B3(c) which is the resulting $C_{\text{obs}}(\theta)$ vs $\theta$ curve after subtraction of background. The background subtracted is represented by (constant $\times t_i$), where $t_i$ is the time (following the time of the first point of a given $C_{\text{obs}}(\theta)$ vs $\theta$ curve) corresponding to the $i^{\text{th}}$ point of the given curve.

(b)(c)(d) $C_{\text{obs}}(\theta)$ vs $\theta$ for Pass 454 ARGUS Event 2 radiation after loop closure is accomplished.
Fig. B4. \(C(\theta)\) and \(J(\theta')\) vs \(\theta\) and \(\theta'\) for the \(C_{\text{obs}}(\theta)\) vs \(\theta\) curves (Fig. B3), Pass 454 ARGUS Event 2. The bars on curves indicate the scatter in calculated values of \(J(\theta')\) as above (Fig. B2).


<table>
<thead>
<tr>
<th>Time (min)</th>
<th>hwhm (deg)</th>
<th>(J(\theta')_{\text{max}})</th>
<th>(B) (gauss)</th>
<th>(L) (earth radii)</th>
</tr>
</thead>
<tbody>
<tr>
<td>310.178</td>
<td>12.0</td>
<td>(3.2\times10^7)</td>
<td>.2720</td>
<td>2.120</td>
</tr>
<tr>
<td>310.223</td>
<td>24.0</td>
<td>(5.65\times10^7)</td>
<td>.2726</td>
<td>2.124</td>
</tr>
<tr>
<td>310.279</td>
<td>13.0</td>
<td>(5.95\times10^7)</td>
<td>.2740</td>
<td>2.128</td>
</tr>
<tr>
<td>310.336</td>
<td>14.0</td>
<td>(6.45\times10^7)</td>
<td>.2742</td>
<td>2.144</td>
</tr>
<tr>
<td>310.496</td>
<td>19.0</td>
<td>(2.82\times10^6)</td>
<td>.2764</td>
<td>2.172</td>
</tr>
</tbody>
</table>

B10
Table E3. Summary of results, Natural and ARGUS radiations

<table>
<thead>
<tr>
<th>Pass No.</th>
<th>Max flux density $J(\theta')$ (cm$^{-2}$sec$^{-1}$ster$^{-1}$)</th>
<th>hwhm (deg)</th>
<th>B.L. (gauss, earth radii)</th>
<th>Time UT (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>414*</td>
<td>$7.3 \times 10^7$</td>
<td>21</td>
<td>0.158, 1.38</td>
<td>249.049-249.302</td>
</tr>
<tr>
<td></td>
<td>$5.6 \times 10^7$</td>
<td>27</td>
<td>0.166, 1.41</td>
<td>250.004-250.559</td>
</tr>
<tr>
<td>427*</td>
<td>$1.2 \times 10^8$</td>
<td>16</td>
<td>0.149, 1.366</td>
<td>227.500-229.000</td>
</tr>
<tr>
<td></td>
<td>$6.5 \times 10^7$</td>
<td>20</td>
<td>0.171, 1.447</td>
<td>231.000-232.000</td>
</tr>
<tr>
<td></td>
<td>$2.7 \times 10^7$</td>
<td>15</td>
<td>0.198, 1.580</td>
<td>234.000-235.000</td>
</tr>
<tr>
<td>454*</td>
<td>$5.0 \times 10^7$</td>
<td>27</td>
<td>0.157, 1.35</td>
<td>299.000-299.217</td>
</tr>
<tr>
<td>454</td>
<td>$4.9 \times 10^7$</td>
<td>17.5</td>
<td>0.178, 1.414</td>
<td>301.221-301.681</td>
</tr>
<tr>
<td></td>
<td>$4.7 \times 10^7$</td>
<td>17.5</td>
<td>0.181, 1.434</td>
<td>301.915-302.143</td>
</tr>
<tr>
<td>453***</td>
<td>$4.5 \times 10^5$</td>
<td>23</td>
<td>0.155</td>
<td>188.300</td>
</tr>
<tr>
<td>479***</td>
<td>$4.5 \times 10^5$</td>
<td>29</td>
<td>0.155</td>
<td>145.450</td>
</tr>
</tbody>
</table>

Continued on next page
Table B3. (continued)

ARGUS Radiation

<table>
<thead>
<tr>
<th>Event, time following Event, Pass No.</th>
<th>Max flux density $J(\theta')$ (cm$^{-2}$sec$^{-1}$ster$^{-1}$)</th>
<th>hwhm (deg)</th>
<th>B.L (gauss, earth radii)</th>
<th>Time UT (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 + 1.8 hr, 414*</td>
<td>$2.0 \times 10^8$</td>
<td>28</td>
<td>.221, 1.68</td>
<td>256.083-256.144</td>
</tr>
<tr>
<td></td>
<td>$2.3 \times 10^8$</td>
<td>24</td>
<td></td>
<td>256.177-256.209</td>
</tr>
<tr>
<td></td>
<td>$7.8 \times 10^7$</td>
<td>25</td>
<td></td>
<td>256.282-256.315</td>
</tr>
<tr>
<td>1 + 3.67 hr, 415##</td>
<td>$1.96 \times 10^8$</td>
<td>32</td>
<td>.24 , 1.70</td>
<td>367.5 -368.0</td>
</tr>
<tr>
<td>1 + 35.48 hr, 427*</td>
<td>$1.6 \times 10^7$</td>
<td>19</td>
<td>.213, 1.675</td>
<td>236.0 -236.5</td>
</tr>
<tr>
<td></td>
<td>$2.6 \times 10^7$</td>
<td>27</td>
<td>.217, 1.724</td>
<td>236.5 -236.68</td>
</tr>
<tr>
<td></td>
<td>$6.7 \times 10^7$</td>
<td>21</td>
<td>.219, 1.739</td>
<td>236.69 -236.85</td>
</tr>
<tr>
<td></td>
<td>$1.6 \times 10^7$</td>
<td>32</td>
<td>.220, 1.740</td>
<td>236.871-237.0</td>
</tr>
<tr>
<td></td>
<td>$1.3 \times 10^7$</td>
<td>24</td>
<td>.224, 1.757</td>
<td>237.0 -237.1</td>
</tr>
<tr>
<td></td>
<td>$2.3 \times 10^7$</td>
<td>20</td>
<td>.22 , 1.7</td>
<td>236.5 -237.0</td>
</tr>
<tr>
<td>1 + 39.13 hr, 440##</td>
<td>$1.96 \times 10^7$</td>
<td>18</td>
<td>.22 , 1.7</td>
<td>216. -217.</td>
</tr>
<tr>
<td>2 + 1.87 hr, 454</td>
<td>$5.65 \times 10^7$</td>
<td>24</td>
<td>.273, 2.124</td>
<td>310.223-310.276</td>
</tr>
<tr>
<td></td>
<td>$5.95 \times 10^7$</td>
<td>13</td>
<td>.274, 2.128</td>
<td>310.279-310.333</td>
</tr>
<tr>
<td></td>
<td>$6.45 \times 10^7$</td>
<td>14</td>
<td>.274, 2.144</td>
<td>310.336-310.413</td>
</tr>
</tbody>
</table>
Table B3. (continued)

<table>
<thead>
<tr>
<th>Pass</th>
<th>Max flux density$^#$ $J(\theta')$ (cm$^{-2}$sec$^{-1}$ster$^{-1}$)</th>
<th>hwhm (deg)</th>
<th>Time UT (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>414 Natural</td>
<td>$1.6 \times 10^4$</td>
<td>30</td>
<td>247.800-249.270</td>
</tr>
<tr>
<td>414 Natural</td>
<td>$1.4 \times 10^4$</td>
<td>32</td>
<td>248.270-250.740</td>
</tr>
<tr>
<td>414 Natural</td>
<td>$1.4 \times 10^4$</td>
<td>26</td>
<td>250.740-252.200</td>
</tr>
<tr>
<td>414 Natural</td>
<td>$1.3 \times 10^4$</td>
<td>24</td>
<td>252.200-253.850</td>
</tr>
<tr>
<td>414 Natural</td>
<td>$1.4 \times 10^4$</td>
<td>26</td>
<td>253.850-255.060</td>
</tr>
<tr>
<td>414 Natural</td>
<td>$1.6 \times 10^4$</td>
<td>38</td>
<td>255.060-256.450</td>
</tr>
<tr>
<td>414 ARGUS</td>
<td>$2.0 \times 10^4$</td>
<td>256.950-257.000</td>
<td></td>
</tr>
<tr>
<td>415 Natural</td>
<td>$1.4 \times 10^4$</td>
<td>25</td>
<td>367.420-369.080</td>
</tr>
<tr>
<td>415 Natural</td>
<td>$1.2 \times 10^4$</td>
<td>22</td>
<td>369.080-370.770</td>
</tr>
<tr>
<td>415 ARGUS</td>
<td>$1.4 \times 10^4$</td>
<td>39</td>
<td>373.920-374.220</td>
</tr>
<tr>
<td>415 ARGUS</td>
<td>$1.7 \times 10^4$</td>
<td>33</td>
<td>374.670-375.220</td>
</tr>
<tr>
<td>427 Natural</td>
<td>$1.6 \times 10^4$</td>
<td>34</td>
<td>236.670-238.340</td>
</tr>
<tr>
<td>427 Natural</td>
<td>$1.5 \times 10^4$</td>
<td>37</td>
<td>238.340-240.000</td>
</tr>
<tr>
<td>427 Natural</td>
<td>$1.5 \times 10^4$</td>
<td>32</td>
<td>240.000-241.670</td>
</tr>
<tr>
<td>427 Natural</td>
<td>$1.2 \times 10^4$</td>
<td>26</td>
<td>241.670-245.000</td>
</tr>
<tr>
<td>427 ARGUS</td>
<td>$1.0 \times 10^4$</td>
<td>30</td>
<td>245.470-246.270</td>
</tr>
<tr>
<td>428 Natural</td>
<td>$1.4 \times 10^4$</td>
<td>31</td>
<td>347.550-350.220</td>
</tr>
<tr>
<td>428 Natural</td>
<td>$1.4 \times 10^4$</td>
<td>25</td>
<td>349.220-352.550</td>
</tr>
</tbody>
</table>

* Taken from Manson (B2)
*** Lundquist-Weber et al (B5)
# J. Bock (B4) Not corrected for counter response function and deadtime
## J. M. Paikeday (B3)
C. Summary of Ph.D. Dissertation, John A. George, "Omnidirectional Fluxes; Explorer 4 Satellite Data, ARGUS Events 1 and 2", Saint Louis University, Physics Department (February 1967).

C1. Introduction

In August and September 1958, three low yield nuclear detonations (ARGUS Events 1, 2, 3) were produced at high altitude over the south Atlantic Ocean. Electrons emitted were subsequently trapped in the geomagnetic field. The characteristics of this radiation were measured by instruments on board Jason sounding rockets and in the Satellite Explorer 4. A number of papers have appeared in which the results of what is known as the ARGUS Experiment were described (Refs. C1, C2, C3).

The present Dissertation is concerned with further analysis of data obtained by Explorer 4 for ARGUS Events 1 and 2 for the G-M Detectors C (Channel 3) and D (Channel 1); therefore data for omnidirectional radiation is considered.

C2. Experimental Details

The characteristics of satellite Explorer 4 (1958 Epsilon) have been described in detail by Van Allen (Ref. C2). For later calibration information, as used in the present report, see Preface P2 of this report. The Anton 302 G-M counters only are involved in the present analysis. A summary of the characteristics of these two detectors is given in Table C1. These detectors are omnidirectional and do not differentiate the kinds of particles being detected. However for the ARGUS radiation, it will be assumed that the predominant contribution to the counting rates is by electrons resulting from the fission processes. Anton 302 G-M counters similar to those on Explorer 4
have since been flown on a number of satellites, and it has been concluded (Refs. C4, C5, C6) that the counting rates must be attributed to penetrating electrons of $E_e > 1.5$ MeV. Motz and Carter (Ref. C7) studied the response of Anton 302 counters to fission-spectrum electrons. They found that up to $2 \text{ gm/cm}^2$ of lead-absorber thickness the curves were as expected for $\beta$-transmission; however, for energies beyond this range the transmission was enhanced somewhat by bremsstrahlung. Detector C (the "unshielded" G-M counter, Channel 3) is shielded by 1.2 $\text{gm/cm}^2$ of stainless steel, which is equivalent to a shielding of 1.46 $\text{gm/cm}^2$ of aluminum. The extrapolated range $R_E$ ($\text{gm/cm}^2$) versus energy $E(\text{MeV})$ for aluminum given by Marshall and Ward (Ref. C8) is

$$R_E = 0.528E - 0.094 \quad \text{(C1)}$$

For Detector C, $R_E$ by Eq. (1) corresponds to 2.95 MeV electrons (Table C2); for Detector D (the "shielded" G-M counter, Channel 1) which had an additional shielding of 1.6 $\text{gm/cm}^2$ of lead, the total shielding is equivalent to 3.89 $\text{gm/cm}^2$ of aluminum and $R_E$ corresponds to 7.6 MeV electrons. For the unshielded Detector C at least the assumption of electrons being counted directly seems quite valid. However, the count-rate of the shielded Detector D may be enhanced somewhat by bremsstrahlung. A plot of the omnidirectional geometrical factors versus the energy necessary to penetrate the various thickness of material, using the information of Tables C1 and C2, is given in Fig. C1.

An automatic digitizer was used to analyze the telemetry playback data and transform it to punch cards. A computer program was
written to obtain count-rate versus time for each selected Pass of the Satellite Explorer 4 over Huntsville, Alabama. The observed count-rates $C_{\text{obs}}$ (sec$^{-1}$) were corrected for the deadtime of the detectors and associated electronics to obtain true count-rates $C$ (sec$^{-1}$) by using the approximation (instead of Eq. (D1), p. D2 below)

$$C_{\text{obs}} = \frac{C_{\text{obs}}}{1 - T_{\text{dead}} C_{\text{obs}}}$$  \hspace{1cm} (C2)

where deadtime $T_{\text{dead}}$ is 62.5 microsecs (Ref. C2) and was confirmed in the present work. Figure C2 is typical of the data available for analysis.

The B and L coordinates for the ARGUS region were obtained from GE TEMPO Data Center (Santa Barbara, California) through the offices of the Defense Atomic Support Agency. Figure C3 shows the regions of interest traversed by Explorer 4 in B-L space for typical Passes over Huntsville, Alabama. Table C3 lists the complete set of Passes analyzed and are arranged in three columns, each of which corresponds to nearly the same region of space relative to the earth. The orbital frequency of Explorer 4 was about 13 orbits per day.

In order to investigate the possible correlation of Explorer 4 ARGUS count-rates with solar activity, 3-hr $K_p$ indices are presented by Fig. C4 for the period under investigation 27 August to 4 September 1958. Subsequent to the large geomagnetic fluctuations observed at the onset, a period of decreasing activity to relative magnetic quiet levels followed. No sudden commencements were observed until 3-5 September, a period which is classified as one of magnetically disturbed days.
C3. Results

ARGUS Event 1

The decay of the fission produced electrons trapped in the earth's magnetic field is indicated in Fig. C5, a log-log plot of the true count-rate versus $T_e$, the elapsed time since Event 1, at a fixed $L$ value. The plotted points are the true omnidirectional count-rates of the unshielded G-M counter (Detector C, Channel 3). The count-rates are differences between total and estimated background rates, and are for the 414, 427, ...518 sequence of Passes. The maximum intensities observed are well represented by the $L = 1.72$ shell. The peak location did not shift, at least within the experimental error, from this $L$ shell during the time interval indicated. If it is assumed $C$ (sec$^{-1}$) versus $t$(hrs) is given by

$$C = C_0 t^{-n},$$  \hspace{1cm} (C3)

where $C_0$ and $n$ are undetermined constants, a least squares fit of the data for $L = 1.72$ yields $n = 1.13$, $C_0 = 1.31 \times 10^5$; whence Eq. (C3) becomes

$$C = 1.31 \times 10^5 t^{-1.13}, \hspace{0.5cm} 0.19 < B < 0.23. \hspace{1cm} (C4)$$

This $t^{-1.13}$ law agrees quite well with the decay rate determined by Cladis and Walt (Ref. C3) from Jason rocket data for ARGUS Event 2 ($L = 2.1$).

Figure C6 is a plot of the count-rate ratio unshielded/shielded omnidirectional G-M counters. Data for shielded and unshielded G-M counter of rates greater than 10 sec$^{-1}$ and 30 sec$^{-1}$ respectively, only were used to eliminate data averaged over larger regions of space.
The data for Pass 414 may be in considerable error due to saturation of the counters. The vertical bars are estimates of the spread of data arising principally from the scatter in the count-rates of the shielded G-M counter. The count-rate ratios terminate at Pass 466 due to the difficulty of separating the ARGUS electrons from the natural background radiation. The dashed line is the plot of $C = C_0 t^{-1.13}$. Of interest is the sudden broadening of the ARGUS Event 1 shell subsequent to Pass 453, Fig. C7. The shell width at half-maximum is given in terms of $\Delta L$. Pass 453 was the first pass to record the effect of Event 2 but all data of Fig. C7 are for Event 1. However, Event 2 occurred subsequent to the satellite traversing the Event 1 Pass 453 shell. Since Passes up to 492 occurred during a period of low geomagnetic activity ($K_p < 3.0$) it is suggested that the broadening observed on Fig. C7 is due to ARGUS Event 2.

Figure C14, a 3-dimensional plot of true count-rate vs B and L, summarizes the data analyzed for the unshielded G-M counter (Detector C, Channel 3) for ARGUS Event 1.

ARGUS Event 2

The data analyzed for ARGUS Event 2 is over a smaller time interval than Event 1. Figure C8 gives the true count-rate versus elapsed time since Event 2. Again the data is for count-rates above the estimated background. The peak intensities were centered very nearly at $L = 2.11$. Pass 453 was the first to indicate ARGUS Event 2, 0.03 hours after the event. Considering the location of the satellite ($297^\circ$ E, $27^\circ$ N) and the detonation ($352^\circ$ E, $50^\circ$ S), fission electrons would need to have energies in excess of 19 MeV to reach the satellite position in...
their eastward drift in the 108 seconds (Ref. C25). Although there is a significant number of MeV-range β-electrons available from the β-decay spectra of fission products, the β-decay end point energies are well below 19 MeV. Hence the initial count-rate may be due to direct illumination by γ-rays emitted by the fission debris. The bomb debris would have to expand to a higher altitude than the detonation point (about 480 km) in order to be in the line of sight of the satellite. Colgate (Ref. C9) discusses the mass motion of a high altitude nuclear explosion. He assumes that the detonation products produce a cavity in the magnetic field and, in general, the hole will expand until the work done against the magnetic field equals the kinetic energy of the detonation products. When the expansion of the detonation plasma products ceases, the subsequent motion will be a spreading along the lines of force away from the detonation hemisphere. This occurs in the order of seconds according to Colgate. With the debris distributed along the lines of force for L = 2.11, the satellite would be in a position to detect the emitted γ-rays.

The decay rates of ARGUS Event 2 are very nearly represented by a $1/t$ law if the data for Passes 466-492 are considered. However, Passes 505 and 518 indicate increases in count-rate in a manner difficult to explain (Fig. C9). A sudden commencement of solar activity did occur shortly after Pass 505 and 3-5 September are listed as magnetically disturbed days.

It is noted that the shielded G-M counter (Detector D, Channel 1) had very low count-rates for the sequence of Passes analyzed for ARGUS Event 2. These were typically less than 20 sec$^{-1}$. Figure C10 shows the count-rate ratio of the unshielded/shielded G-M counter for the L
shell of peak intensity ($L = 2.11$) for Passes 466-492. Subsequent to
Pass 492 the ARGUS Event 2 electrons detected by the shielded counter
were indistinguishable from the natural radiation.

C4. ARGUS Loss Mechanisms

The effect of the atmosphere on the decay of the trapped electrons
has been calculated using a Fokker-Planck approach to derive a diffusion
equation (Ref. C10). This technique was applied by Salt (Ref. C11), also
Walt and Newkirk (Ref. C12) to the observed time variation produced by
the Starfish nuclear explosion. In regions of the magnetosphere for
which $L = 1.3$, it was found that the dominant factor limiting the
trapping time of electrons is scattering by components of the atmosphere.
However, for $L = 1.3$ the decay of trapped electrons is dominated by
other loss mechanisms of electromagnetic-hydromagnetic character.

A breakdown of the adiabatic invariants which will eventually
enhance the atmosphere losses has been proposed by a number of authors.
The processes responsible for the violation of the third adiabatic
invariant have been considered by Parker (Ref. C13), Davis and Chang
(Ref. C14), and Nakada and Mead (Ref. C15). Large scale geomagnetic
fluctuations associated with sudden commencements and the initial phase
of geomagnetic storms can cause diffusion of electrons across $L$ shells.
However, the dominant effect would be in the outer radiation zone,
and repeated magnetic storms would seem to be necessary for rapid dif-
fusion. The exact analytic details are quite complicated and have not
been attempted so far in the present work - however the concept is
highly suggestive. Sudden commencements were observed on August 27
at 0243, 0303, and 0541 hrs UT. Pass 414 traversed the ARGUS Event 2
region at approximately 0456 UT, 1.8 hours after the event. No further
sudden commencements were observed until September 3 and 4 which coincide with Passes 505 and 518 respectively.

The effect of several other electromagnetic-type loss contributing factors have been studied by workers in this field, as follows. Resonant particle-wave interaction in which the magnetic moment invariance is violated has been studied by Wentzel (Ref. C16), Dragt (Ref. C17), and also Chang and Pearlstein (Ref. C18). A summary of Dragt's work (Ref. C17) on the effect of hydromagnetic waves is given by Fig. C11. Critical energies below which the magnetic moment is conserved in interactions with hm waves are shown for particles mirroring at latitudes greater than 30 degrees assuming the hm wave frequency is cut off sharply at $\omega_{\text{max}}$. Various cut-off frequencies are indicated as it is assumed that hm waves may vary from 1 to 5 sec$^{-1}$ up to the local proton cyclotron frequency. It is clear that such frequencies would not be very effective in interaction with ARGUS electrons. Wentzel gives a qualitative discussion to the effect that hm waves could influence the mirror point distribution of the relativistic ARGUS electrons during a geomagnetic storm. This may be a contributing factor to the large loss observed within the first day which was active magnetically.

Again, the precipitation of electrons through the action of whistlers has been investigated by Dungey (Ref. C19) and by Cornwall (Ref. C20). For resonant interaction to take place, the Doppler-shifted frequency of the whistler as seen by the electron must be equal to the relativistic cyclotron frequency of the moving electron. Figure C12 summarizes Cornwall's results showing the L dependence of the precipitating particles with increasing electron energy. The ARGUS
Events 1 and 2 regions are shown, indicating, at least qualitatively, that whistlers may not be a major mechanism driving electrons to larger $B$ values.

Also, Paulikas et al (Ref. C21) suggest longitudinal waves propagating along magnetic field lines would interact with electrons at their mirror points and would be an efficient loss mechanism. These electrostatic waves may be able to move electrons to larger $B$ values in times of the order of days.

Further detailed theoretical investigations are needed before quantitative results may be given to adequately explain the rapid decay of the ARGUS electron shells.

C5. Conclusions

The analysis of the data obtained by the omnidirectional G-M counters (Detectors D, C; Channels 1, 3) carried by Explorer 4 for the ARGUS Events 1 and 2 can be summarized as follows.

The two Events are centered on the $L = 1.72$ and $L = 2.11$ shells respectively. The locations of the peak intensities did not vary, at least within experimental error, from these values during the time of observation. The ARGUS Event 1 region showed a decay law of $t^{-1.13}$ for $E_e > 3$ MeV. The count-rate ratio of the unshielded to the shielded counter was found to decrease with time. This indicates spectral changes occur which is in apparent contradiction with the results of the published Jason rocket data. A general broadening of the ARGUS Event 1 region was observed subsequent to the detonation of ARGUS Event 2. The increase in the width at half-maximum was by a factor of 1.5. ARGUS Event 2 seemed to be influenced to a greater degree.
than ARGUS Event 1 by the magnetically disturbed days of September 3-5.
McIlwain (Ref. C22) theorized that magnetic storms produce a decrease in electron flux which occurs so quickly that it is difficult to follow and then is followed by an increase larger than normal. The observed increases on Passes 505 and 518 of Event 2 may be related to these magnetic storm effects. The larger value L shells of Event 2 compared to Event 1 may account for the variation of the storm influence. Although a general decrease in count-rate ratios were observed for both events, ARGUS Event 2 was not as sharp as the first event and may point to L dependence of the decaying fission spectrum. The data is too limited to determine the precise nature of this dependence.

The decay of the ARGUS Event 1 region was found to follow a $t^{-1.13}$ law. It may be coincidental that this is nearly identical to the fission product decay law. The fission fragment $\beta$-ray source strength decays approximately according to a $t^{-1.2}$ law (Ref. C23). Measurements indicate that although the $t^{-1.2}$ decay represents a reasonable average there have been instances where exponents in the range -0.9 to -2.0 are required to represent the rate of decay.

Figure 13, from Heller (Ref. C24), gives the number of beta rays per fission from $^{235}\text{U}$ per energy interval versus time for various energies. The ratio of high energy to low energy $\beta$-rays decreases with time. This contradicts the results of Figs. C6 and C10 which indicated the unshielded/shielded count-rate ratio that is, $C(E_\beta > 3 \text{ MeV})/C(E_\beta > 7.6 \text{ MeV})$, decreases with time. Further study is required on the lifetimes of the fission debris which is trapped in the earth's geomagnetic field.

A brief study was conducted of possible mechanisms which would
explain the rapid decay of the ARGUS Events. Theories involving the breakdown of the adiabatic invariants have been proposed by a number of workers. The author (J. George) applied these theories to the ARGUS data. Computations indicate that hydromagnetic waves and whistler interactions resulting in the violation of the first invariant are not, at least qualitatively, major mechanisms in removing ARGUS electrons. Although resonant particle-wave interactions, and other processes such as diffusion, may operate, they do not dominate. Further theoretical work is necessary to determine the controlling mechanism for the ARGUS decay.

Adiabatic processes such as betatron acceleration and deceleration cannot be excluded in any detailed analysis of irreversible loss mechanisms. The effect of slow changes in the magnetic field upon the omnidirectional intensity of particles was considered and calculations for the ARGUS time period show that the changes are not inconsequential. By making conservative assumptions concerning the change in the magnetic field during the main phase decrease following Pass 414, it was shown that the relative intensity could change by 15% due to the betatron acceleration alone.

C6. References.


C22. McIlwain, C. E., comment in Illinois Institute of Technology Report T6118 (1965); "Radiation Trapped in the Earth's Magnetic Field"
Table C1 (Ref. C2) Characteristics of G-M counters, Explorer 4

<table>
<thead>
<tr>
<th>Detector</th>
<th>D (Channel 1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&quot;Shielded&quot; Geiger-Mueller counter (Anton 302) Cylinder approximately 7 mm x 9 mm Scalar: 64</td>
<td></td>
</tr>
<tr>
<td>&quot;Unshielded&quot; Geiger-Mueller counter (Anton 302) Cylinder approximately 7 mm x 9 mm Scalar: 2048</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Shielding</th>
<th>1.2 gm/cm² Fe + 1.6 gm/cm² Pb (minimum)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1.2 gm/cm² Fe (minimum)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sensitive to:</th>
<th>Electrons of Eₜ &gt; 5 MeV, Protons of Eₜ &gt; 40 MeV, X-rays of E &gt; 80 KeV with low efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Electrons of Eₜ &gt; 3 MeV, Protons of Eₜ &gt; 30 MeV, X-rays of E &gt; 20 KeV with low efficiency</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Geometric Factor:</th>
<th>Omnidirectional geometric factor G₀: 0.14 cm² for minimum stopping power, 0.82 cm² for penetrability greater than 7 gm/cm²</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Omnidirectional geometric factor G₀: 0.14 cm² for minimum stopping power, 0.70 cm² for penetrability greater than 5 gm/cm²</td>
</tr>
</tbody>
</table>

C14
<table>
<thead>
<tr>
<th>Detector</th>
<th>Shielding (gm/cm$^2$)</th>
<th>Equivalent Al. (gm/cm$^2$)</th>
<th>Energy (MeV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>1.2 Fe</td>
<td>1.46</td>
<td>2.95</td>
</tr>
<tr>
<td>D</td>
<td>1.2 Fe + 1.6 Pb</td>
<td>3.89</td>
<td>7.6</td>
</tr>
</tbody>
</table>
Table C3. Explorer 4 Passes "over" Huntsville, Alabama selected for omnidirectional radiation analysis

ARGUS Event 1 (time of burst: 0230 UT August 27, 1958)

<table>
<thead>
<tr>
<th>Date</th>
<th>Pass</th>
<th>Pass</th>
<th>Pass</th>
</tr>
</thead>
<tbody>
<tr>
<td>August 27, 1958</td>
<td>414</td>
<td>415</td>
<td>416</td>
</tr>
<tr>
<td>28</td>
<td>427</td>
<td></td>
<td></td>
</tr>
<tr>
<td>29</td>
<td>440</td>
<td></td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>453</td>
<td>454</td>
<td></td>
</tr>
<tr>
<td>31</td>
<td>466</td>
<td></td>
<td></td>
</tr>
<tr>
<td>September 1, 1958</td>
<td>479</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>492</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>505</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>518</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

ARGUS Event 2 (time of burst: 0320 UT August 30, 1958)

<table>
<thead>
<tr>
<th>Date</th>
<th>Pass</th>
<th>Pass</th>
<th>Pass</th>
</tr>
</thead>
<tbody>
<tr>
<td>August 30, 1958</td>
<td>453</td>
<td>454</td>
<td>455</td>
</tr>
<tr>
<td>31</td>
<td>466</td>
<td></td>
<td></td>
</tr>
<tr>
<td>September 1, 1958</td>
<td>479</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>492</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>505</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>518</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Fig. Cl. Geometrical factor, $G_0$ (cm$^2$), versus the energy (MeV) necessary for transmission by the various thicknesses of materials. Circled points are from Table C2, using Eq. (Cl), assuming a linear dependence of $G_0$ with $E$ between plotted points and constant values for larger energies (as shown).
Fig. C2. Omnidirectional count-rates vs time for a typical Pass of Explorer 4 in the ARGUS Event 1 region. The solid lines are average count-rates drawn through points not shown.

Curve A. Unshielded G-M counter (Detector C, Channel 3) which detects electrons of energy greater than 3 MeV. The background has been drawn in by estimation.

Curve B. Shielded G-M counter (Detector D, Channel 1) which detects electrons of energy greater than 7.6 MeV. The background has been drawn in by estimation.

Curve C. Ratio of A/B, unshielded to shielded G-M count-rates. The ratios are of count-rates above the background.

Curve D. Difference A - B, unshielded minus shielded G-M count-rates above the background. This curve shows the omnidirectional count-rates due to electrons between 3 and 7.6 MeV, a roughly "monoenergetic" count-rate curve.
Fig. C3. Path of satellite Explorer 4 in B-L coordinates. The regions of ARGUS Events 1 and 2 are shown also.
Fig. C4. Planetary magnetic three-hour range $K_p$ indices during the time interval of ARGUS Events 1 and 2.
PLANETARY THREE-HOUR-RANGE INDICES $K_p$ (1958)

PASS NUMBER

$414$ $427$ $440$ $453$ $466$ $479$ $492$ $505$ $518$

AUGUST

SEPTMBER

△ sudden commencement
Fig. C5. Logarithmic plot of true count-rate of the unshielded G-M counter (Detector C, Channel 3) versus the elapsed time since detonation of ARGUS Event 1. The solid lines are least squares fit of Eq. (C3) for the data of the sequence of Passes 414, 427, ... 518. \( n = 1.13 \) for both curves. Intersection of the two straight lines with the ordinate axis yield values of \( C_0 \), Eq. (C3). The peak intensities were centered at \( L = 1.72 \).
Fig. C6. Count-rate ratio, unshielded (Channel 3)/shielded (Channel 1) omnidirectional G-M counters versus elapsed time $T_e$ since ARGUS Event 1. Both G-M count-rates were corrected for background count-rates. The dashed line is the plot of $C = C_0 t^{-1.13}$, Eq. (C3).
Fig. C7. The geometrical width at half-maximum of the ARGUS Event 1 region versus the elapsed time $T_e$ since the event. (Pass 453 was the first to contain ARGUS Event 2 data.)
Fig. C8. True count-rate of the unshielded (Detector C, Channel 3) G-M counter versus the elapsed time $T_e$ since ARGUS Event 2 for selected L shells.
Fig. C9. Logarithmic plot of true count-rate of the unshielded G-M counter (Detector C, Channel 3) vs the elapsed time $T_e$ since ARGUS Event 2 for selected L shells. Passes 505 and 518 were during a period of high magnetic activity.
Fig. C10. Count-rate ratio, unshielded (Channel 3)/shielded (Channel 1) G-M counter vs elapsed time $T_e$ since ARGUS Event 2. $L = 2.11$ is the region of peak intensity of the ARGUS Event 2 region. The numbers above the plotted points are satellite Pass (over Huntsville, Alabama) numbers.
Fig. C11. Critical energies below which the magnetic moment is conserved in interactions with hydromagnetic waves for particles mirroring at geomagnetic latitudes greater than 30° assuming the hm wave is cut off sharply at $V_{\text{max}}$. Shown are $V_{\text{max}} = 1, 5, \text{ and } V_{\text{sec}}^{-1}$ (Ref. C19).
\( \lambda > 30^\circ \)

\( \nu_{\max} = 1 \text{cps} \)

\( E_{\text{critical}} \) (MeV)

\( L \) (earth radii)
Fig. C12. Regions in space where whistlers may be effective in precipitating electrons into the atmosphere. The plot is from Eq. (C4) with the heart of the whistler range being 1 to 10 kc/s (Ref. C20).
REGION OF WHISTLER INTERACTION

ELECTRON ENERGY (MeV)

L (EARTH RADII)
Fig. C13. Number of beta rays per fission from $^{235}\text{U}$ per energy interval for various energies $E$ in units of $m_0c^2$.

The data is taken from Heller (Ref. C24).
Fig. C14. Observed omnidirectional, true initial count-rate $C_0$ contours vs B and L for ARGUS Event 1 (Detector C, unshielded G-M counter, Channel 3). $C_0$ is the true count-rate corrected for decay assuming the $t^{-1.13}$ law, Eq. (C3). The initial time reference for the decay law correction is the beginning of ARGUS shell counting for Pass 427. The solid line count-rate contour curves are best fits to the data from Passes 415, 416, 427, 440, 453, 466, 479 (points not shown).
Fig. C15. Omnidirectional flux density $J_0$ contours vs $B$ and $L$ for ARGUS Event 1 (Detector $C$, unshielded G-M counter, Channel $J$) obtained from the observed omnidirectional true count-rate $C_0$ data (Fig. C14). The conversion is given by $J_0 = 67C_0$. 
OMNIDIRECTIONAL FLUX DENSITY
IN B - L COORDINATES

$J_0 = 0.5 \times 10^5$

$I = 0.67 \times 10^5$

$J = 1.34 \times 10^5$

$2 \times 10^5$

$6.7 \times 10^4$

$L$ (earth radii)

D1. Introduction

The purpose of the present Summary is to present experimental aspects of the trapped radiation, including the omnidirectional charged particle flux densities in the geomagnetic field, for pre-ARGUS event times of Explorer 4 Satellite data telemetered over Huntsville, Alabama. Such an investigation is important toward understanding the "background" radiation (natural radiation) against which the artificially injected ARGUS radiation is observed.

D2. Experimental Details

Instrumentation and Calibration of Explorer 4

The University of Iowa group designed the detection instruments. Van Allen has published a complete description of the detection instruments (Ref. D2). Reference D3, Fig. 2.1, p. 16, shows a block diagram of the four detectors A, B, C and D, and the corresponding telemetry channels 2 and 5, 3 and 1. (See also Preface P2, Fig. P2-1).

For the present thesis the omnidirectional count-rates were analysed, involving data obtained by G-M Detectors C and D. Preface P2 of this Report summarizes the characteristics of Detectors C and D. Table D1 lists the telemetry data available for the present analysis and Fig. D1 shows the location of Satellite Explorer 4 for some of the Passes.

The count-rates of the G-M counters must be corrected for D1.
"deadtimes". For detectors C and D, Anton 302 G-M counters, the equation for the correction is

\[ C_{\text{obs}} = C e^{-\frac{T_d}{\tau_t}} \]  

(D1)

where \( C_{\text{obs}} \) is the observed count-rate and \( C \) is the true or corrected count-rate and \( \tau_t \), the deadtime, is \( 62.5 \pm 1.3 \) microseconds.

Further instrumentation and analysis details are found in DASA Report WT 1613, Ref. (D3).

D3. Results

A complete set of Figures showing the true count-rates vs time for the different B-L regions of the pre-ARGUS Explorer 4 times is found in Ref. Di.

These Ref. Di Figures are here compactly summarized by three new Figs. D2 (constant omnidirectional count-rate contours in B-L coordinates), D3 (omnidirectional flux densities vs B), D4 (three dimensional plots of omnidirectional true count-rates vs B and L).

The slope of \( \log(J_0) \) vs \( \log(B) \) straight line (derived from Fig. D4) compares closely with earlier published results (Ref. D4).

In general it has been found (Ref. D1) that Passes 2, 13, 26, 52, 78, 107, 173, 207 and 367 recorded small flux densities, between 10 and 30 particles cm\(^{-2}\) sec\(^{-1}\); while passes 4, 43, 121, 272, 285, 298, 311, 324, 337, 375 and 401 recorded large flux densities between 100 and 20,000 particles cm\(^{-2}\) sec\(^{-1}\). Passes of small measured flux densities correspond to low altitude (250 < altitude < 700 km). The low count-rates are due chiefly to non-trapped cosmic radiation in space. The Passes of
larger measured altitudes \((1000 < \text{altitude} < 1500)\) are specified by 
\[0.17 < B < 0.30, \ 0.35 < L < 1.65\] and 
\[0.35 < B < 0.45, \ 3.5 < L < 5.5.\]

The larger omnidirectional flux densities were recorded in the Van Allen region.

D4. References


D3
Fig. D1 Map showing location of Satellite 1958E(Explorer 4) for
Passes 2, 4, 13, 26, 43, 52, 63, 78, 107, 121, 172, 207, 272,
285, 298, 311, 324, 337, 367, 375, 401 and 414 tracked by the
U. S. Army Tracking Station at Huntsville, Alabama. Except
for Pass 414, these Passes are for pre-ARGUS times. The
number in parenthesis is the Pass number, the other numbers
are the satellite altitudes at the beginning and end of the
tracking period for the Pass.
Fig. D2 Omnidirectional true constant count-rate contours in B-L coordinates. Data is for pre-A-GUS times, shielded G-M detector D (channel 1) for the region defined by 1.27 < L < 1.30 and 0.20 < B < 0.23. To obtain \( J_0 \), the true omnidirectional count-rates are multiplied by 8.4*, a reduction constant derived from the calibration of the detector.

(*provisional, subject to correction)
Fig. D3 Omnidirectional flux densities vs magnetic flux density B.

Data is for pre-ARGUS times, shielded G-M detector D (channel 1) for the region defined by $0.20 \leq B \leq 0.23$ and $1.27 \leq L \leq 1.30$. Log $J_0$ vs $B$ is plotted instead of log $J_0$ vs log $B$ in order to obtain somewhat greater spread in data. The data may be represented by the equation $J_0 = k B^n$, whence $n = 30$, approximately.
OMNIDIRECTIONAL FLUX DENSITY
VS.
MAGNETIC FLUX DENSITY
CHANNEL 1

\[ J_0 \text{ (particles cm}^{-2} \text{ sec}^{-1}) \]

\[ B \text{ (gauss)} \]

\[ \log(B) \]

\( L = 1.27 \text{ earth radii} \)
\( L = 1.28 \text{ "} \)
\( L = 1.29 \text{ "} \)
\( L = 1.30 \text{ "} \)
Fig. D4 Three dimensional plot of omnidirectional true count-rates $C$ (shielded G-M counter, Detector D, channel 1) (number sec$^{-1}$) vs B and L. Sheets of constant L are shown intersecting the contours of constant count-rates. Data is the same as for Figs. D2 and D3.
CHANNEL 1
TRUE COUNT-RATE
on B-L (three dimensional)
PRE-ARGUS

B (gauss)

TRUE COUNT-RATE
(see-1)

L (earth radii)

○ = ACTUAL DATA POINTS
Table D1. Explorer 4 telemetry, pre-ARGUS times data available at Saint Louis University, Physics Department; Passes are over Huntsville, Alabama Tracking Station.

<table>
<thead>
<tr>
<th>Pass No.</th>
<th>Date</th>
<th>Time</th>
<th>Pass No.</th>
<th>Date</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>July 26</td>
<td>1658-1702</td>
<td>199</td>
<td>Aug. 10</td>
<td>2015-2025</td>
</tr>
<tr>
<td>2</td>
<td>26</td>
<td>1855-1856</td>
<td>207</td>
<td>11</td>
<td>1025-1035</td>
</tr>
<tr>
<td>3</td>
<td>26</td>
<td>2054-2057</td>
<td>208</td>
<td>11</td>
<td>1220-1228</td>
</tr>
<tr>
<td>4</td>
<td>July 27</td>
<td>0036-0042</td>
<td>210</td>
<td>Aug. 12</td>
<td>1010-1021</td>
</tr>
<tr>
<td>5</td>
<td>27</td>
<td>1650-1655</td>
<td>211</td>
<td>12</td>
<td>1807-1815</td>
</tr>
<tr>
<td>13</td>
<td>27</td>
<td>1848-1851</td>
<td>212</td>
<td>Aug. 12</td>
<td>1405-</td>
</tr>
<tr>
<td>15</td>
<td>27</td>
<td>2042-2052</td>
<td>213</td>
<td>12</td>
<td>1754-1801</td>
</tr>
<tr>
<td>16</td>
<td>27</td>
<td>2240-2247</td>
<td>214</td>
<td>Aug. 13</td>
<td>0937-1008</td>
</tr>
<tr>
<td>17</td>
<td>July 28</td>
<td>1449-1451</td>
<td>215</td>
<td>13</td>
<td>1153-1202</td>
</tr>
<tr>
<td>28</td>
<td>28</td>
<td>1642-1648</td>
<td>216</td>
<td>13</td>
<td>1741-1748</td>
</tr>
<tr>
<td>28</td>
<td>28</td>
<td>1840-1844</td>
<td>217</td>
<td>13</td>
<td>1935-1943</td>
</tr>
<tr>
<td>42</td>
<td>July 29</td>
<td>2026-2035</td>
<td>218</td>
<td>Aug. 14</td>
<td>0950-0953</td>
</tr>
<tr>
<td>43</td>
<td>29</td>
<td>2220-2227</td>
<td>219</td>
<td>14</td>
<td>1139-1149</td>
</tr>
<tr>
<td>52</td>
<td>July 30</td>
<td>1430-1437</td>
<td>220</td>
<td>14</td>
<td>1725-1734</td>
</tr>
<tr>
<td>53</td>
<td>30</td>
<td>1627-1632</td>
<td>221</td>
<td>14</td>
<td>1923-1929</td>
</tr>
<tr>
<td>64</td>
<td>July 31</td>
<td>1421-1426</td>
<td>222</td>
<td>Aug. 15</td>
<td>0924-0938</td>
</tr>
<tr>
<td>66</td>
<td>31</td>
<td>1618-1622</td>
<td>223</td>
<td>15</td>
<td>1125-1132</td>
</tr>
<tr>
<td>67</td>
<td>31</td>
<td>1816-1818</td>
<td>224</td>
<td>15</td>
<td>1907-1915</td>
</tr>
<tr>
<td>69</td>
<td>Aug. -1</td>
<td>0000-0007</td>
<td>225</td>
<td>Aug. 16</td>
<td>0910-0920</td>
</tr>
<tr>
<td>70</td>
<td>1</td>
<td>1220-1222</td>
<td>226</td>
<td>16</td>
<td>1107-1118</td>
</tr>
<tr>
<td>77</td>
<td>1</td>
<td>1412-1420</td>
<td>227</td>
<td>16</td>
<td>1657-1705</td>
</tr>
<tr>
<td>78</td>
<td>1</td>
<td>1609-1614</td>
<td>228</td>
<td>16</td>
<td>1852-1858</td>
</tr>
<tr>
<td>79</td>
<td>1</td>
<td>1806-1811</td>
<td>229</td>
<td>Aug. 17</td>
<td>0855-0906</td>
</tr>
<tr>
<td>80</td>
<td>1</td>
<td>2001-2008</td>
<td>230</td>
<td>17</td>
<td>1056-1102</td>
</tr>
<tr>
<td>81</td>
<td>1</td>
<td>2154-2208</td>
<td>231</td>
<td>Aug. 18</td>
<td>0840-0854</td>
</tr>
<tr>
<td>82</td>
<td>1</td>
<td>2205-</td>
<td>232</td>
<td>18</td>
<td>1627-1633</td>
</tr>
<tr>
<td>104</td>
<td>Aug. -3</td>
<td>-0841</td>
<td>234</td>
<td>19</td>
<td>0832-0833</td>
</tr>
<tr>
<td>107</td>
<td>3</td>
<td>1941-1949</td>
<td>235</td>
<td>19</td>
<td>1022-1032</td>
</tr>
<tr>
<td>108</td>
<td>3</td>
<td>2130-2141</td>
<td>236</td>
<td>19</td>
<td>1611-1617</td>
</tr>
<tr>
<td>109</td>
<td>3</td>
<td>2331-2335</td>
<td>237</td>
<td>Aug. 20</td>
<td>0836-0809</td>
</tr>
<tr>
<td>121</td>
<td>Aug. -4</td>
<td>2125-2134</td>
<td>238</td>
<td>20</td>
<td>1004-1015</td>
</tr>
<tr>
<td>122</td>
<td>4</td>
<td>2321-2327</td>
<td>239</td>
<td>20</td>
<td>1555-1602</td>
</tr>
<tr>
<td>133</td>
<td>Aug. -5</td>
<td>1921-1927</td>
<td>240</td>
<td>Aug. 21</td>
<td>0748-0806</td>
</tr>
<tr>
<td>134</td>
<td>5</td>
<td>2113-2126</td>
<td>241</td>
<td>21</td>
<td>0949-0959</td>
</tr>
<tr>
<td>147</td>
<td>Aug. -6</td>
<td>2200-2210</td>
<td>242</td>
<td>21</td>
<td>1538-1544</td>
</tr>
<tr>
<td>148</td>
<td>6</td>
<td>2257-1305</td>
<td>243</td>
<td>Aug. 22</td>
<td>1521-1527</td>
</tr>
<tr>
<td>169</td>
<td>Aug. -7</td>
<td>1327-1305</td>
<td>244</td>
<td>Aug. 23</td>
<td>1503-1510</td>
</tr>
<tr>
<td>172</td>
<td>Aug. -8</td>
<td>1845-1852</td>
<td>245</td>
<td>Aug. 24</td>
<td>0510-0518</td>
</tr>
<tr>
<td>173</td>
<td>8</td>
<td>2030-2050</td>
<td>246</td>
<td>Aug. 26</td>
<td>0433-0440</td>
</tr>
<tr>
<td>182</td>
<td>Aug. -9</td>
<td>1243-1249</td>
<td>247</td>
<td>26</td>
<td>1408-1414</td>
</tr>
<tr>
<td>189</td>
<td>9</td>
<td>1820-1828</td>
<td>248</td>
<td>26</td>
<td>2225-2259</td>
</tr>
</tbody>
</table>
E. Summary of Pertinent Analytic Sections of Ph.D. Dissertation, Joseph M. Paikeday, "Interpretation of Directional Flux Densities in ARGUS Shells, Explorer 4 Satellite Data"; Saint Louis University, Physics Department (March 1966).

El. Introduction

The method used for obtaining the directional flux density \( J(\theta') \) (particles \( cm^{-2} sec^{-1} ster^{-1} \); \( \theta' \), angle between scintillation counter axis \( \hat{P} \) and \( \hat{J} \)) follows that of Lundquist, Naumann, and Weber (Ref. El) in the reduction of the integral equation relating the corrected directional count-rate \( C(\theta) \) (number \( cm^{-2} sec^{-1} \)) and \( J(\theta') \) to matrix form \( \{\theta, angle between \hat{P} and a plane perpendicular to the magnetic flux density vector \( B \}) \). The matrix elements \( S_{ij} \) (Ref. E2, p. 13) associated with the response function have been evaluated to a greater accuracy resulting from a more precise definition in the present analysis of the limits of integration in the integral equation relating \( C(\theta) \) and \( J(\theta') \) (Ref. E2, Eq. (1.6)). It has been found that the kernel of this integral equation has a vanishingly small determinant and as a consequence established methods of solving the integral equation for \( J(\theta') \) values fail to produce physically meaningful results. The kernel of this integral equation is highly sensitive to experimental errors inherent in the \( C(\theta) \) data. The present method replaces the inverse of the kernel matrix by an approximate matrix (Ref. E2, Eq. (1.26)) which is insensitive to small errors in the counting rate data.
E2. Summary of the Analytic Procedure

The complete details of the analytic procedure outlined in El above are given in the Paikeday Ph.D. Dissertation (Ref. E2). The procedure involves the following steps:

1. Reduction of the integral equation to a matrix form (see Ref. E2 pp. 7-13).

2. Representation of the directional scintillation detector (Detector A, Channel 2) response function $S(\alpha)$ (Ref. E2, Fig. 1.2, p. 149) in analytic form (see Ref. E2, Eq. (1.10)) to yield $J(\theta')$ values.

3. Inversion of the matrix equation (see Ref. E2, pp. 14-33).

E3. Conclusions

With the data available as discrete points of the $C(\theta)$ function, the solutions obtained by using the inverse of the $S$-matrix are found to be non-physical. The process of getting correct physical solutions does not in any way remove the ill-conditioning of the original matrix $S$ representing the kernel of the integral equation but rather supplies information about the type of errors that enter the counting rate data.

The method developed in the present analysis is found to yield meaningful $J(\theta')$ values for the available $C(\theta)$ data.

E4. References

### Summary of Ph.D. Dissertation, Donald J. Manson, "Van Allen Radiation Belt and ARGUS Directional Flux Density Distributions, Explorer 4, Satellite Data", Saint Louis University, Physics Department, February 1967.

### Summary of M.S. Thesis of Joseph P. Fennell, "Van Allen Belt and ARGUS Directional Flux Density Distributions, Explorer 4 Satellite Data, ARGUS Event 2", Saint Louis University, Physics Department, July 1966.

### Summary of Ph.D. Dissertation, John A. George, "Omnidirectional Fluxes; Explorer 4 Satellite Data, ARGUS Events 1 and 2", Saint Louis University, Physics Department, February 1967.

### Summary of Pertinent Analytic Sections of Ph.D. Dissertation, Joseph M. Paikeday, "Interpretation of Directional Flux Densities in Geomagnetically Trapped Radiation Explorer 4 pre-ARGUS Times"; Saint Louis University, Physics Department, May 1966.
### Security Classification

#### Analysis of Explorer IV Telemetry Records
- Geomagnetically Trapped Radiation
- Naturally and ARGUS Injected Geomagnetically Trapped Radiation
- Unidirectional and Omnidirectional Geomagnetically Trapped Radiation
- Natural and ARGUS Trapped Radiation in B-L Coordinates

#### Instructions

1. **ORIGINATING ACTIVITY:** Enter the name and address of the contractor, subcontractor, grantee, Department of Defense activity or other organization (corporate author) issuing the report.

2a. **REPORT SECURITY CLASSIFICATION:** Enter the overall security classification of the report. Indicate whether "Restricted Data" is included. Marking is to be in accordance with appropriate security regulations.

2b. **GROUP:** Automatic downgrading is specified in DoD Directive 5200.10 and Armed Forces Industrial Manual. Enter the group number. Also, when applicable, show that optional markings have been used for Group 3 and Group 4 as authorized.

3. **REPORT TITLE:** Enter the complete report title in all capital letters. Titles in all cases should be uncategorized. If a meaningful title cannot be selected without classification, show title classification in all capitals in parenthesis immediately following the title.

4. **DESCRIPTIVE NOTES:** If appropriate, enter the type of report, e.g., interim, progress, summary, annual, or final. Give the inclusive dates when a specific reporting period is covered.

5. **AUTHOR(S):** Enter the name(s) of author(s) as shown on or in the report. Enter last name, first name, middle initial. If military, show rank and branch of service. The name of the principal author is an absolute minimum requirement.

6. **REPORT DATE:** Enter the date of the report as month, year. If more than one date appears on the report, use date of publication.

7a. **TOTAL NUMBER OF PAGES:** The total page count should follow normal pagination procedures, i.e., enter the number of pages containing information.

7b. **NUMBER OF REFERENCES:** Enter the total number of references cited in the report.

8a. **CONTRACT OR GRANT NUMBER:** If appropriate, enter the applicable number of the contract or grant under which the report was written.

8b. & 8c. **PROJECT NUMBER:** Enter the appropriate military department identification, such as project number, subproject number, system number, task number, etc.

9a. **ORIGINATOR'S REPORT NUMBER(S):** Enter the official report number by which the document will be identified and controlled by the originating activity. This number must be unique to this report.

9b. **OTHER REPORT NUMBER(S):** If the report has been assigned any other report numbers (edit or by the originator or by the sponsor), also enter this number(s).

10. **AVAILABILITY/LIMITATION NOTICES:** Enter any limitations on further dissemination of the report, other than those imposed by security classification, using standard statements such as:

   (1) "Qualified requesters may obtain copies of this report from DDC"
   (2) "Foreign announcement and dissemination of this report by DDC is not authorized"
   (3) "U.S. Government agencies may obtain copies of this report directly from DDC. Other qualified users shall request through DDC.
   (4) "U.S. military agencies may obtain copies of this report directly from DDC. Other qualified users shall request through DDC."
   (5) "All distribution of this report is controlled. Qualified DDC users shall request through DDC."

If the report has been furnished to the Office of Technical Services, Department of Commerce, for sale to the public, indicate this fact and enter the price, if known.

11. **SUPPLEMENTARY NOTES:** Use for additional explanatory notes.

12. **SPONSORING MILITARY ACTIVITY:** Enter the name of the departmental project office or laboratory sponsoring (paying for) the research and development. Include address.

13. **ABSTRACT:** Enter an abstract giving a brief and factual summary of the document indicative of the report, even though it may also appear elsewhere in the body of the technical report. If additional space is required, a continuation sheet shall be attached.

It is highly desirable that the abstract of classified reports be unclassified. Each paragraph of the abstract shall end with an indication of the military security classification of the information in the paragraph, represented as (TS), (S), (C), or (U).

There is no limitation on the length of the abstract. However, the suggested length is from 150 to 225 words.

14. **KEY WORDS:** Key words are technically meaningful terms or short phrases that characterize a report and may be used as index entries for cataloging the report. Key words must be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location, may be used as key words but will be followed by an indication of technical context. The assignment of links, rules, and weights is optional.